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INVESTIGATION OF THE LATERAL VIBRATION CHARACTERISTICS OF A 1/5-SCALE MODEL OF SATURN SA-1

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SUMMARY

The results of bending vibration tests on a 1/5-scale model of the Saturn SA-1 launch vehicle are presented. The model was designed by using the replica scaling technique, all important structural, elastic, and dynamic features of the full-scale vehicle being duplicated to 1/5 scale. For the tests reported herein, free-free boundary conditions were simulated by using a two-cable suspension system.

The vibration modes, frequencies, and damping were determined at five weight conditions corresponding to different points in the launch trajectory. These conditions were 100, 75, 48, 25, and 0 percent of the booster propellant load at lift-off. The results presented show the unusual frequency spectrum and mode shapes of the Saturn vehicle which result from its clustered configuration. In addition to the usual bending modes, cluster modes were found in which the various tanks within the booster cluster had motion relative to each other.

INTRODUCTION

For a space launch vehicle to accomplish its mission successfully, the vehicle must maintain its structural integrity and be controllable. Proper design of the structure and control system requires a knowledge of the vibration characteristics of the vehicle because of the possibility that vibrations can cause critical stresses in the structure or instabilities in the control system. One of the usual methods of determining the vibration characteristics is to conduct an experimental ground vibration survey of a full-scale vehicle. In the field of liquid-fuel rocket vehicles the required ground vibration surveys have increased in cost and difficulty simply because of the increasing size and resulting structural complexity of the vehicles. The present trend is toward larger and still more complex vehicles.

In order to obtain the desired vibration characteristics with less cost and effort than are required for a full-scale ground vibration survey, it is natural to consider the use of a reduced-scale dynamic model. The success of dynamic models in providing valuable information in such fields as aircraft stability and aeroelasticity leads to the expectation that, with sufficient development, scaled dynamic models will also make significant contributions to the field of launch-vehicle dynamics.

In order to provide data to help establish the feasibility of using models to obtain vibration data, as well as to study the vibration characteristics of a clustered-tank configuration, a 1/5-scale dynamic replica model of the Saturn SA-1 vehicle has been constructed and its vibration characteristics investigated at the Langley Research Center. This model was designed and constructed to duplicate as nearly as possible all important structural features of the full-scale vehicle. Detailed results of the investigation of the vibration characteristics of the 1/5-scale Saturn model in a simulated free-free condition are presented herein, together with a complete description of the model. Some of these results are presented in preliminary form in references 1 and 2, and comparisons of these preliminary data with preliminary results of a similar investigation of a full-scale vehicle, conducted at Marshall Space Flight Center, are presented in reference 3. On the basis of the preliminary data it is concluded in reference 3 that studies of structural replica models are very useful in defining the vibration characteristics of large launch vehicles. Future comparisons of the detailed model results presented herein with final results of the full-scale tests will allow more detailed conclusions to be drawn.

SYMBOLS

E Young's modulus, lb/sq in.

f frequency, cps

G acceleration of gravity

g damping factor

I area moment of inertia, in.^{4}

I' mass moment of inertia, lb-in-sec^2

l length, in.

m mass, lb-sec^2/in.

n number of cycles used in determining damping

x_o initial vibration amplitude

x_n vibration amplitude after n cycles

μ Poisson's ratio

ρ mass density, lb-sec^2/in.^{4}

Subscripts:

F full scale

M model

1/5-SCALE SATURN MODEL

Scaling

The 1/5-scale model of the Saturn SA-1 launch vehicle was constructed for the purpose of investigating vibration characteristics; therefore, the important parameters to be considered in scaling were the mass and stiffness magnitudes and distributions. The type of scaling chosen was a component-by-component uniform reduction of dimensions to one-fifth of the full-scale values. This type of scaling was chosen because of the structural complexity of the Saturn launch vehicle with the resulting difficulty of determining accurate equivalent stiffness and mass properties for the many multiple beam trusswork assemblies incorporated in the vehicle. Scaling of linear dimensions determined the scale factor of 1/5 from practical considerations of the minimum material thickness required for satisfactory fabrication. Accurate scaling of the stiffness distribution was insured by scaled reproduction of all important structural members, particularly the fittings joining the components together, and by using on the model the same materials as used on the full-scale vehicle. An accurate mass distribution was obtained by substituting lead ballast weights for the nonstructural components such as aerodynamic fairings and fuel piping which were omitted from the model.

From these considerations the following scale factors were determined:

Selected values:

Typical lengths

$$\frac{L_M}{L_F} = \frac{1}{5}$$

Material properties

$$\frac{E_M}{E_F} = \frac{\rho_M}{\rho_F} = \frac{\mu_M}{\mu_F} = 1$$

Computed values:

Mass

$$\frac{m_M}{m_F} = \frac{\rho_M}{\rho_F}\left(\frac{L_M}{L_F}\right)^3 = \frac{1}{5^3}$$

Mass moment of inertia

$$\frac{I'_M}{I'_F} = \frac{\rho_M}{\rho_F}\left(\frac{L_M}{L_F}\right)^5 = \frac{1}{5^5}$$

Cross-section moment of inertia

$$\frac{I_M}{I_F} = \left(\frac{L_M}{L_F}\right)^4 = \frac{1}{5^4}$$

Bending frequency

$$\left(\frac{f_M}{f_F}\right)_{bend} = \left[\frac{EI_M}{EI_F}\,\frac{m_F}{m_M}\left(\frac{L_F}{L_M}\right)^3\right]^{1/2} = 5$$

Sloshing frequency

$$\left(\frac{f_M}{f_F}\right)_{slosh} = \left(\frac{L_F}{L_M}\right)^{1/2} = 5^{1/2}$$

Shell frequency

$$\left(\frac{f_M}{f_F}\right)_{shell} = \frac{L_F}{L_M}\left(\frac{E_M\rho_F}{E_F\rho_M}\right)^{1/2} = 5$$

where the subscripts F and M indicate full-scale and model values, respectively.

Since the bending frequencies scale directly with the scale factor, whereas the sloshing frequencies scale with the square root of the scale factor, the full-scale bending-sloshing frequency relationship is not maintained on the model. Thus, the interaction of vehicle bending with sloshing on the model will not represent directly the full-scale situation. For a configuration such as Saturn where the first sloshing frequency is smaller than the first bending frequency, the reduction to model size separates the frequencies, thus tending to uncouple the sloshing from the bending modes. The shell frequency relationship is obtained from reference 4 and is based on an unstiffened shell with the same internal pressure in both model and full scale. Comparison of the bending and shell frequency relationships shows that interaction of local shell vibrations with vehicle bending vibrations will be the same on the model as on the full scale, provided that the model construction and internal pressure are the same as the full-scale values.

Description

A drawing of the 1/5-scale Saturn model showing some pertinent dimensions and nomenclature to be used herein is presented in figure 1 and a photograph of the model suspended in the vibration testing tower is shown in figure 2. The model consists of three stages and a conical payload section; it is 388.6 inches (32 feet, 4.6 inches) in over-all length, the booster stage is 53 inches in over-all diameter, and the total weight is about 7,400 pounds when ballasted to simulate the lift-off weight condition.

Measured values of weight (dry and water filled), center-of-gravity location, and mass moment of inertia about the center of gravity, for each stage and the complete model are given in table I. Water was used in the model to simulate the mass of the fuel and lox. Substitution of water for fuel and lox is considered to result in only small errors in the results because the densities of fuel and lox are not very different from that of water and because the water level was adjusted to obtain the proper scaled total model weight. Mass and bending stiffness distributions were calculated from the known dimensions and material properties of the model and are presented in figures 3 to 6. The bending stiffness of the barrel (stations 21 to 49) and the second-stage adapter (stations 174 to 195) was scaled from estimates of the stiffness of the full-scale components made at the Marshall Space Flight Center.

First stage.- The principal components of the booster (first) stage of the model are a 21-inch-diameter center tank, eight 14-inch-diameter outer tanks which surround the center tank, a connecting corrugated barrel and outrigger structure at the lower end, and a connecting spider beam at the upper end. The barrel and outriggers are shown in figure 7 and a view of the spider beam and second-stage adapter area is shown in figure 8. The center tank is firmly attached to the barrel at the lower end and to the spider beam and second-stage adapter at the upper end, and forms the principal load-carrying structure of the booster; this structure is shown in figure 9 during assembly of the booster. The outer tanks are attached to this structure by two joints at each end of each tank. A sketch of these joints is presented in figure 10 and a photograph of the upper joints is presented as figure 11. The full-scale Saturn is designed to carry liquid oxygen in the center tank and in the four alternating outer tanks having the type of upper joint shown at the left of figure 10(a). Fuel is carried in the full-scale Saturn in the other four outer tanks, which have the type of upper joint shown at the right of figure 10(a). For convenience, the model outer tanks will be called "lox" or "fuel" tanks according to the type of upper joint. The fuel-tank upper joints are constructed to allow for contraction of the center and four outer lox tanks when filled with the cold liquid oxygen. The type of joint used (shown in fig. 10(a)) will not transmit longitudinal load; therefore, the fuel tanks sustain no longitudinal load except for internal pressure loads and the inertia load of their own structural weight. The lox-tank joints will transmit longitudinal compressive loads, and therefore the lox tanks sustain, along with the center tank, some of the upper-stage inertia loads. The outer-lox-tank joints may be adjusted to obtain a range of preload compressive forces. At their lower end, all eight outer tanks are attached to the outrigger by means of the type of joint shown in figure 10(b).

Upper stages.- The second stage consists of an outer shell which is connected by means of eight radial truss assemblies to an inner water ballast tank. A photograph of the second stage taken from the aft end and showing the inner tank, the eight radial trusses, and the outer shell is shown as figure 12. The outer shell is the principal structural member of the second stage; it supports the weight of the ballast tank, which constitutes 70 percent of the second-stage weight when water filled, and the weight of the third stage. The third stage consists simply of a water ballast tank which also supports the nose-cone weight of 14 pounds, which includes the weight of a simulated payload.

Simulated engines.- A photograph showing the simulated engines incorporated on the model is presented as figure 13. These engines were designed to simulate only the center-of-gravity location, total weight, and the moment of inertia about the gimbal point of the full-scale engines. The mass parameters are listed in the following table:

	Inboard engines	Outboard engines
Weight per engine, lb	12.9	13.5
Distance from gimbal point (station 20) to center of gravity, in.	6	6
Moment of inertia about gimbal point, lb-in.^{2}	1,043	1,097

Inboard engines are those attached directly to the corrugated barrel; outboard engines are those attached to the outriggers. Figure 13 shows that all engines were fixed at the gimbal point; no provision was made for the engines to move with respect to the gimbal point, and actuators were not simulated on the model. The natural frequencies of the engines were determined and the resulting values are given in table II. The engines themselves are rotationally symmetrical; the two frequencies of each engine shown in table II indicate that there is considerable nonsymmetrical flexibility in the attachment of the engines to the model.

APPARATUS

Suspension System

The two-cable suspension system illustrated in figure 14 was used to hold the model during testing. This suspension system was developed at the Langley Research Center for use in vibration testing. The model weight is supported through the outriggers by a support yoke which is attached to two vertical cables which are attached to a pair of movable rollers at the top of the test tower. The support yoke and the vertical cable can be seen in figure 7. The distance between the rollers is adjustable by means of turnbuckles located at the base of the test tower. The rollers at the top of the tower on their support track can be seen in figure 2. Stability of the model is provided by a restraining cable located at the top of the third stage as illustrated in figure 14. The restraining force can be varied by varying the distance between rollers. As an example, when the booster is emptied, the center of gravity of the model is moved upward toward the midsection and the instability is thereby increased. In order to compensate for this, the distance between the rollers is increased; thus, the model is stabilized through the increased tension of the restraining cables.

The restraint of the two-cable suspension adds to the system a rigid-body pendulum mode and a rigid-body rocking mode. The frequency of the pendulum mode is dependent on the length of the vertical cables and varies very little with the distance between the rollers; however, the rocking frequency can be varied over a wide range by changing the distance between the rollers. Decreasing the distance between the rollers decreases the tension in the horizontal restraining cables with a resultant decrease in the frequency of the rocking mode. The frequency of the rocking mode can theoretically be reduced to zero for small motions of the model. However, the restoring force of the restraining cables varies nonlinearly with the model deflection so that the model is supported vertically even though the rocking frequency is zero.

Shaker System

Electromagnetic shakers having a capacity of 50 vector pounds of force were used to vibrate the model. The shakers were oriented to apply the force normal to the plane of the vertical suspension cables. For most of the tests a single shaker was used. It was attached at model station 24 to a bracket connected to two outriggers as shown in figure 7. For a few of the tests two shakers were used, one at station 24 and another at station 345, the junction of the nose cone and the third-stage ballast tank. These shakers were operated either in or out of phase, depending on the mode under investigation.

Instrumentation

Deflection and vibration frequency of the model were obtained from accelerometers mounted on brackets attached to the skin of the model. The location of these "fixed" accelerometers is shown in figure 15, and a typical accelerometer attachment is shown in figure 8.

In addition to the fixed accelerometers, an accelerometer provided with a vacuum attachment was used as a portable pickup to survey parts of the model not covered by the fixed pickups. The entire model, including the outer tanks, was accessible with this setup. The deflection of the second-stage outer shell was measured with the portable accelerometer in the plane of the shaking force and with the fixed accelerometer at model station 207 (hereinafter called accelerometer 207). In figure 15, section B-B, accelerometer 207 is shown to be out of the plane of the shaking force as indicated by the arrow. The accelerometer is oriented, however, to indicate deflection parallel to the plane of the shaking force. It is shown that differences between the deflections in the shaking plane and at accelerometer 207 indicate the presence of shell motion of the second-stage outer shell. Accelerometer output was fed through carrier amplifiers and recorded on an oscillograph.

In addition to the instrumentation required to measure dynamic response, strain gages were placed on all four of the outer lox tanks to measure static longitudinal load. These strain gages were placed around the periphery of the midsection and were used to measure the compressive load resulting from adjustment of the lox-tank pin connections.

PROCEDURE

General

In all the testing performed, the second and third stages of the model were maintained fully ballasted with water. Different vehicle configurations were obtained by varying the water level in the booster. Vibration test results were obtained for the following vehicle configurations:

Booster water level, percent full	Simulated flight condition	Model weight, lb
0	Burnout	2,415
25	------------------------	3,650
48	Maximum dynamic pressure	4,790
75	------------------------	6,125
100	Lift-off	7,360

The 100-percent-full booster water level refers to the water level at the lift-off weight condition; the booster tanks are not completely full in this condition.

Model Preparation

The water level in the booster was first adjusted to give the desired weight configuration. Air pressure was then introduced into the booster and third-stage tanks to raise the frequencies of the local vibration modes and thus decrease their interference with the bending modes, which were of primary interest. A pressure of 5 lb/sq in. was maintained in the third-stage and booster outer tanks, and 10 lb/sq in. in the booster center lox tank. These pressure levels were maintained throughout the entire testing program.

In order to insure stability before ballasting the model, the distance between the suspension-cable rollers was increased to the maximum allowed by the vibration-tower construction. Following ballasting, the distance was decreased until the restraining cable tension was just enough to support the model vertically. The rigid-body rocking frequency thus obtained was about 0.25 cps for all weight conditions. (The rigid-body pendulum frequency was calculated to be 0.20 cps or less.) The leveling alinement of the model in the plane perpendicular to the shaking plane was made by adjustment of the turnbuckles in the support cables.

Finally, the outer-lox-tank pin adjustments were made. For most of the tests described herein 40 percent of the total weight of the second and third stages was carried by the four outer lox tanks of the booster; the remaining 60 percent was supported by the center lox tank. Initially, the lox-tank upper joints were loosened, relieving any compressive loading on the lox tanks, and the strain gages were zeroed. Then, the lox-tank joints were gradually tightened until the desired loading was obtained. The tanks were loaded gradually in pairs composed of diametrically opposite tanks. After the desired strain was indicated for each outer lox tank, lock nuts were tightened at each pin-type connection to insure against any possible loosening during the tests.

Testing

At each weight configuration, the first test operation was a frequency sweep with constant shaker force over a given frequency range. With the booster 48 percent full, a range of frequency from about 5 cps to about 90 cps was covered; for the other weight conditions, the range covered was from about 5 cps to about 45 cps. The output of the fixed accelerometers was recorded and used to determine the approximate frequencies of the resonant response peaks. Then, a survey of the vibration mode at each of the response peaks was made by tuning the frequency of the shaker to produce maximum response of the model. The survey consisted of recordings of the response of the fixed accelerometers and recordings of the response of the portable accelerometer as it was attached to intermediate locations between the fixed accelerometers and to the outer tanks and engines. In order to determine if shell mode interference existed and to determine the direction of motion of the booster outer tanks, surveys were made with the portable accelerometer. For this part of the survey, the outputs of the portable accelerometer and a suitable reference accelerometer were displayed on an oscilloscope for visual observation. The positions of the vertical node lines were determined by observing the change of phase as the portable accelerometer was moved around the circumference of the outer tanks. All mode shapes, including those of the outer tanks, were measured in the plane of maximum response. Damping decrements were obtained by instantaneously cutting the input to the shaker at the frequency of the natural mode of interest. The damping values were obtained from the output of the fixed accelerometers which was recorded on an oscillograph. The decaying amplitude was read from the oscillograph and plotted on semilogarithmic paper, and a straight line faired through the data. The damping factor g was obtained from the relation:

$$g = \frac{1}{n\pi} \log_e \frac{x_o}{x_n}$$

where

x_o initial vibration amplitude

x_n amplitude after n cycles

RESULTS AND DISCUSSION

Resonant frequencies and the associated mode shapes and damping of the model were determined with the booster from 0 percent to 100 percent full of water. A summary of the frequencies and damping values is presented in table III, and details of the mode shapes are presented in tables IV to XXII. The mode shapes obtained with the booster 48 percent full (weight condition corresponding to maximum dynamic pressure) are typical of the results for other water levels; therefore, these results are discussed in detail.

Results With Booster 48 Percent Full

Frequency response.- The variation of the deflection of the tip (station 386) with frequency is presented in figure 16. Also presented in this figure are natural frequencies calculated by using elementary beam theory (rotary inertia and shear effects were not included). For these calculations a bending stiffness EI of 320×10^7 lb-in.^{2} was used for the booster (stations 0 to 195) and the bending stiffness given in figure 3 was used for the upper stages. The bending stiffness of the booster was scaled from estimates of the bending stiffness of the full-scale booster made at Marshall Space Flight Center. The experimental curve in figure 16 shows that there were eight major response peaks (indicating the resonant frequencies), whereas only three calculated natural frequencies occurred in this range of frequency. This indicates that the theory used herein, with its simplifying assumption of a single equivalent stiffness for the booster, does not adequately represent the Saturn vehicle over the whole frequency range of interest. The calculated and experimental frequencies occurring at 13.0 cps are in good agreement; however, the other calculated frequencies do not correspond with any of the experimental resonances. The calculated bending-mode frequency of 28.5 cps is fairly close to the experimental resonance of 26 cps; however, it is shown that the mode shape associated with the experimental resonance at 26 cps is not a bending mode. The mode shapes associated with the first six experimental resonant frequencies have been identified and are presented in figures 17 to 23.

First bending mode.- The mode shape and damping associated with the first response peak, 13.0 cps, are shown in figure 17. The normalized deflection of the model main structure and a typical outer tank are presented. Main structure deflection includes the deflections of the corrugated barrel, the booster center tank, the outer shell of the second stage, the second-to-third-stage connector, and the third-stage tank and cone. At the right of this figure the direction of motion of the engines, at station 0, and all booster tanks, section A-A, is indicated by the arrows. (A similar manner of presenting mode shapes is used in subsequent figures.)

This figure shows that the booster center tank and the typical outer tank have about the same deflection, as indicated by the normalized deflection curve. In addition, section A-A shows that all the outer tanks are deflecting in the same direction as the center tank. When the booster-outer-tank deflections are predominantly in the same direction and with about the same amplitude as the center tank, as they are in this mode, the mode is termed a "bending mode." This particular mode is identified as the first bending mode. This type of motion does not always occur and examples are shown in subsequent figures.

All the engines are shown to be moving together in the same direction as the barrel, to which they are attached. As the natural frequencies of the engines (shown in table II) are approached, the engine motion becomes erratic. The damping values g presented for two amplitudes show that as the amplitude decreased the damping value decreased also.

First cluster mode.- The mode shape and damping associated with the second response peak, 26.0 cps, are shown in figure 18. The normalized deflection shows that, in this case, the center tank and outer tank 3 are deflecting in opposite directions. Section A-A shows that all outer tanks are deflecting in a direction predominantly opposite to the center-tank deflection and that the four lox tanks (tanks 2, 4, 6, and 8) have a component of motion out of the plane of the applied force. This unusual mode is the result of the clustered arrangement of the booster tanks and is therefore termed a "cluster mode." This particular mode is identified as the first cluster mode.

The damping values are again smaller for the smaller amplitudes. Also, all engines deflect in the same direction as the barrel to which they are attached.

Second cluster mode.- The mode shape associated with the third response peak, 33.9 cps, is shown in figure 19. In this cluster mode (the second cluster mode) the center tank is deflecting in the same direction as the tip, whereas outer tank 7 is deflecting in the opposite direction. For comparison, in the first cluster mode the center-tank deflection is opposite to the tip deflection, whereas the outer tanks are deflecting in the same direction as the tip (station 386). All outer-tank motions could not be identified because of interference from local vibrations; however, the outer-tank deflections which were identified, as shown by section A-A, are predominantly opposite to the center-tank deflection. The lox tanks again have a component of motion out of the plane of the applied force.

The deflections of all engines could not be identified, and those that were identified were not uniformly deflected in the direction of the barrel, as shown in the engine motion sketch. This irregular engine motion can be understood by considering the engine vibration characteristics as shown in table II. Table II shows two different natural frequencies of each engine, the lower frequency being in the plane perpendicular to the outrigger and in the frequency range from 35 cps to 40 cps. (As was mentioned previously, the engines have different frequencies in the two planes as a result of dissymmetry of the barrel structure to which they are attached.) Also, each engine has a different frequency. When the shaker force is applied at an angle to the predominant planes of the engines, as indicated by the arrow in table II, each engine will tend to respond with a component of motion in the plane perpendicular to its outrigger where its natural frequency is lowest. The magnitude of the component depends on the ratio of the natural frequency of the engine to the forcing frequency. Thus, with the forcing frequency of this mode, 33.9 cps, each engine has a considerable component of motion which is not in the plane of the shaker force, and each component is different depending on the engine natural frequency and the angle between the shaker plane and the outrigger plane.

Second bending mode.- The mode shape associated with the fourth response peak, 38.9 cps, is shown in figure 20. This mode is identified as a bending mode (second bending mode) because the outer tanks are deflecting in the same direction and with approximately the same amplitude as the center tank, as shown by the normalized deflection curve and by the booster section A-A. The frequency of this mode is in the range of the engine natural frequencies; this tends to account for the erratic engine behavior shown in this figure.

The normalized deflection curve shows two values of deflection in the area of the second stage, one for the center line and one for the second-stage ballast tank. Figure 20 shows that the ballast tank and the outer shell are deflecting in opposite directions, a phenomenon which can be explained by reference to a cross section of the second stage.

The deflections of both the ballast tank and the outer shell are shown for several points on the circumference in figure 21. This figure shows that the outer shell is deflecting in a shell mode, with 14 nodal points around the circumference, while the ballast tank is translating with an essentially undeformed circular cross section. Thus, the large deflections of the center line shown in figure 20 are the result of local deformations of the load-carrying outer shell and involve only small amounts of mass. Most of the second-stage mass is incorporated in the ballast tank which deflects in the opposite direction. This phenomenon emphasizes the importance of measuring the deflections of all components having large mass and the importance of complete measurement of a mode for adequate understanding of the data.

Third bending mode.- The mode shape associated with the fifth response peak, 47.8 cps, is shown in figure 22. The mode is identified as a bending mode because the outer tanks are deflecting in the same direction and with approximately the same amplitude as the center tank, as shown by the normalized deflection curve and the booster section A-A. The shape of the main structure curve in the second-stage area, which is similar to the curve shown in figure 20, and the deflection of accelerometer 207, which was measured out of the plane of the shaking force, indicates that a shell mode may exist in the second stage. However, the second-stage cross-section mode was not identified for verification of this indication.

The role of the engines in the identification of this mode is interesting. Although the frequency of this mode is only slightly above the engine natural frequencies, the engine deflections, while slightly erratic, are predominantly all in the same direction as the tip (station 386). Thus, the main structure has only three node points (which is characteristic of a second bending type of mode); however, inclusion of the engines adds a fourth node point and the mode is thus characterized as the third bending mode.

Fourth bending mode.- The mode shape and damping associated with the sixth response peak, 60 cps, are shown in figure 23. Again, the booster outer tanks are shown to be deflected generally in the same direction as the center tank and with approximately the same amplitude. Also, shell deflections appear to be present in the second stage, as indicated by the deflection of accelerometer 207 (the flagged symbol) which was measured out of the plane of the shaking force. In order to get five node points (a characteristic of a fourth bending mode), the contribution of the engines must be considered; however, in this case it must be assumed that the contributions of engines 2 and 6 are small, since they are deflected in the opposite direction from the rest of the engines.

Results for All Model Weights

Variation of frequency with booster water level.- The variation of resonant frequency with booster water level, expressed as percent full with 100 percent full being the lift-off water level, is shown in figure 24. This figure shows that the cluster modes were not observed at the water levels of 0 and 25 percent full. In general, the various modes retain their characteristics shown in figures 17 to 23 as the booster water level is changed. For example, in the first cluster mode the deflection relationship between the center tank and the outer tanks of the booster and the general appearance of the mode shape, as shown by the normalized deflection, is the same for all weight conditions as for 48 percent full shown in figure 18. The mode shape associated with the third response peak at 100 percent full, however, is an exception.

Outer-tank mode at 100 percent full.- The mode shape associated with the response at 9.4 cps with the booster 100 percent full is shown in figure 25. This figure shows that there is very little deflection of the main structure, and the only identifiable deflection of the outer tanks was for outer fuel tanks 1 and 5. The figure shows that the mode shape consists principally of response of the outer fuel tanks in their first bending mode.

Third vehicle response at 100 percent full.- The mode shape associated with the third response peak with the booster tanks 100 percent full is shown in figure 26. Comparison of this figure and figure 19, the second cluster mode at 48 percent full, shows substantial differences between the booster deflections in the two modes. Figure 19 shows that with the booster tanks 48 percent full the outer-tank deflections are opposite to the center-tank deflection over most of the outer-tank length; however, figure 26 shows that with the booster 100 percent full the outer-tank deflection is in the same direction as the center-tank deflection over nearly one-half of the outer-tank length. Thus, while the frequency of the response varies in a continuous manner with booster water level, the mode shape associated with this response undergoes a change of character as the water level changes.

Nonlinearity of Response

The variations of tip deflection and resonant frequency with shaker force are shown in figure 27, for outer-tank compressive force values of 0, 900, and 1,800 pounds with the booster tanks 48 percent full. These curves were obtained by varying the shaker frequency with a given shaker force until maximum deflection of the first response peak occurred. Figure 27(a) shows that model deflection is not a linear function of shaker force, and figure 27(b) shows that frequency decreases with an increase of shaker force. The damping values presented in table III indicate that damping increases with an increase of vibration amplitude. This variation of damping with amplitude might be expected to cause a corresponding change of frequency with amplitude such as that shown in figure 27(b). However, the change of frequency which can be calculated from the damping values given in table III is too small to account for the frequency change shown in figure 27(b); this indicates that nonlinear effects other than a variation of damping with amplitudes are present. This figure also shows the effect on amplitude and frequency of varying the outer-tank compressive forces. Figure 27(a) shows that for a given value of shaker force the amplitude increases with an increase of compressive force in the outer tanks. Figure 27(b) shows that frequency increases with increasing outer-tank compressive force.

Spider-Beam Deflections

An investigation was made of the deflections of one arm of the spider beam with the purpose of determining the relationship between the deflections of the model center line (center tank and cylindrical structure of second-stage adapter) and the local spider-beam deflections. The spider beam is one possible location for guidance instrumentation, and it was therefore desired to know whether slopes measured on the spider beam would accurately represent the center-line slope.

Deflections of the spider-beam arms were measured with the booster tanks 48 percent full and with the model vibrating in each of the natural frequencies for that weight. The results are presented in figure 28 along with faired center-line curves. The curves in this figure show that local bending of the spider beam is taking place and that the slope near the ends of the spider beam can be substantially different from the center-line slope.

CONCLUDING REMARKS

An investigation of the vibration characteristics of a 1/5-scale dynamic replica model of the Saturn SA-1 has been performed and the results reported herein. The results consist of the resonant frequencies and the associated mode shapes and damping of the 1/5-scale model with the booster tank water level varying from 0 percent full (simulated burnout condition) to 100 percent full (simulated lift-off condition).

These results show the unusual response characteristics of the Saturn model associated with the clustered arrangement of the booster tanks. The number of resonant frequencies obtained on the model has been shown to be significantly greater than the number of natural frequencies calculated by simple beam theory with an equivalent overall stiffness assigned to the booster. The mode shapes associated with the additional resonant frequencies have shown significant independent behavior of the tanks in the clustered booster, indicating that, in calculations of frequencies and modes, each of the tanks must be considered independently.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., October 10, 1962.

REFERENCES

1. Mixson, J. S., and Catherine, J. J.: Investigation of Vibration Characteristics of a 1/5-Scale Model of Saturn SA-1. Shock, Vibration and Associated Environments - Pt. IV. Bull. No. 30, Office of Sec. of Defense, Apr. 1962, pp. 30-39.

2. Runyan, Harry L., Jr., and Rainey, A. Gerald: Launch-Vehicle Dynamics. NASA TM X-607, 1961.

3. Rainey, A. Gerald, and Runyan, Harry L.: Structural Dynamics Aspects of the Manned Lunar Space Vehicle Launch Phase. [Preprint] 513C, Soc. Automotive Eng., Apr. 1962.

4. Mixson, John S., and Herr, Robert W.: An Investigation of the Vibration Characteristics of Pressurized Thin-Walled Circular Cylinders Partly Filled With Liquid. NASA TR R-145, 1962.

TABLE I

SUMMARY OF STATIC CHARACTERISTICS FOR 1/5-SCALE MODEL OF SATURN SA-1

	Length, in.	Dry weight, lb	Total weight (booster 100 percent full), lb	Center-of-gravity (dry) station, in.	Moment of inertia about center of gravity (dry), lb-in-sec^2
Booster (includes engines and second-stage adapter	195.9	630	5,575	75.7	6,460
Second stage (includes third-stage adapter)	105.3	215	935	241.9	530
Third stage (includes nose cone)	98.3	75	850	338.5	69.1
Total model	388.6	920	7,360	136.0	

TABLE II

NATURAL FREQUENCIES OF 1/5-SCALE SATURN ENGINES

Engine	Frequency, cps	
	Radial	Tangential
1	45.0	39.8
2	39.2	35.0
3	45.8	35.0
4	38.8	36.9
5	45.2	38.2
6	44.0	38.1
7	46.0	38.2
8	39.2	37.0

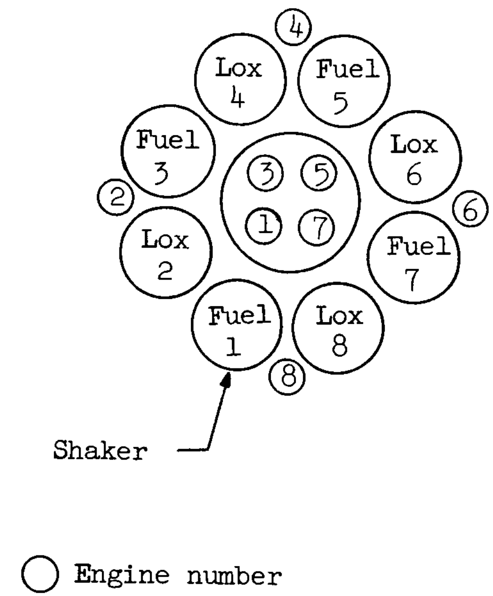


TABLE III

SUMMARY OF RESONANT FREQUENCIES AND ASSOCIATED DAMPING FOR 1/5-SCALE MODEL

Mode	0 percent full (burnout)		25 percent full		48 percent full (maximum dynamic pressure)		75 percent full		100 percent full (lift-off)	
	Frequency, cps	Damping, g	Frequency, cps	Damping, g	Frequency, cps	Damping, g	Frequency, cps	Damping, g	Frequency, cps	Damping, g
Outer fuel tank	----	---------------	----	-----	----	---------------	----	-------------	9.1	---------------
First bending	13.4	0.030 and 0.017	13.6	0.052	13.0	0.032 and 0.017	12.1	0.020	10.5	0.033 and 0.025
First cluster	----	---------------	----	-----	26.0	.023 and .011	20.8	.025 and .015	18.4	.017
Second cluster	----	---------------	----	-----	33.9	---------------	27.6	.022 and .016	24.0	.014
Second bending	44.7	.046 and .032	44.6	-----	38.9	---------------	36.9	.039 and .019	30.6	.010
Third bending	----	---------------	----	-----	47.8	.017	----	-------------	----	---------------
Fourth bending	----	---------------	----	-----	60.0	.011 and .007	----	-------------	----	---------------

TABLE IV

NORMALIZED FIRST BENDING MODE SHAPE FOR BOOSTER EMPTY

[Frequency, 13.4 cps; amplitude, 1 G peak-to-peak at station 386]

Force input (shakers in phase):
Shaker 1 at station 24, 22 vector lb
Shaker 2 at station 345, 22 vector lb

Damping at station 386:
When $x_o(G) = 0.18$, $g = 0.03$
When $x_o(G) = 0.105$, $g = 0.017$

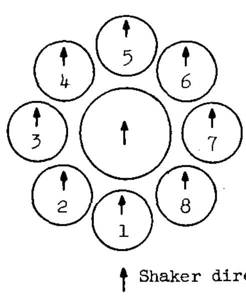
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
385.5	1.00	285	0.01	184	-0.63
375	.85	282	.02	180	-.60
365	.75	275	-.07	176	-.70
355	.66	265	-.14	174	-.68
346	.58	255	-.17	164	-.65
341	.51	245	-.26	144	-.50
335	.51	235	-.32	113	-.31
325	.43	225	-.39	84	-.08
315	.31	215	-.46	54	.18
306	.19	207	-.48	35	.35
304	.20	205	-.54	29	.38
295	.07	195	-.53	24	.44

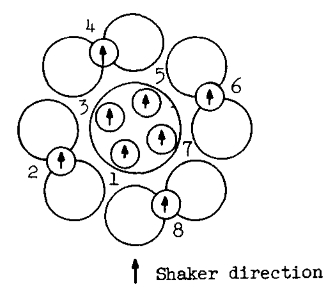
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	0.33	0.34	0.32	0.33	0.34	0.32	0.34	0.34
58	.25	.22	.22	.23	.12	.18	.23	.25
78	.13	----	.11	.11	.11	.11	.14	.13
98	-.12	-.23	-.17	-.23	-.22	-.20	-.21	-.27
118	-.40	-.34	-.30	-.40	-.35	-.35	-.34	-.41
138	-.52	-.51	-.50	-.52	-.56	-.55	-.53	-.54
158	-.60	-.56	-.58	-.63	-.56	-.65	-.56	-.63
173	-.69	-.66	-.65	-.67	-.65	-.70	-.63	-.64



Booster cross section - station 60



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	0.68	0.76	0.79	0.65	0.74	0.74	0.78	0.79
10	.57	.65	.62	.48	.61	.59	.57	.59
20	.45	.47	.48	.47	.48	.51	.45	.45

TABLE V

NORMALIZED SECOND BENDING MODE SHAPE FOR BOOSTER EMPTY

[Frequency, 44.7 cps]

Damping at station 164:
When $x_o(G) = 0.40$, $g = 0.046$
When $x_o(G) = 0.051$, $g = 0.032$

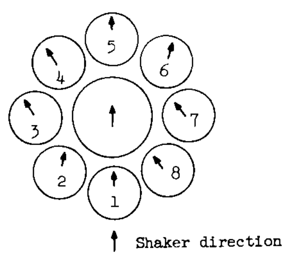
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	265	0.32	173	0.98
385	1.00	255	.62	164	1.03
375	.91	245	.85	144	1.08
365	.75	235	.86	113	.89
355	.63	225	.94	84	.45
346	.49	215	1.09	54	.07
341	.45	205	1.01	35	-.22
335	.47	194	.67	29	-.27
325	.21	184	.72	24	-.31
295	-.20	180	.87		
275	.32	176	.99		

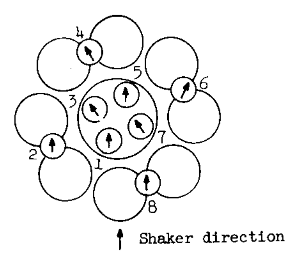
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	-0.016	-0.14	-0.17	-0.14	-0.17	-0.11	-0.30	-0.18
48	.15	-----	-----	-----	-----	-----	-----	-----
58	.42	.26	.14	.28	.48	.32	.35	.34
68	.68	-----	-----	-----	-----	-----	-----	-----
78	.83	.57	.52	.59	.89	.41	.55	.60
88	1.08	-----	-----	-----	-----	-----	-----	-----
98	1.32	.92	.75	.92	1.36	.51	.92	.94
108	1.51	-----	-----	-----	-----	-----	-----	-----
118	1.60	1.09	1.02	1.26	1.58	.67	1.18	1.18
128	1.75	-----	-----	-----	-----	-----	-----	-----
138	1.66	1.23	1.11	1.35	1.73	.68	1.42	1.23
148	1.53	-----	-----	-----	-----	-----	-----	-----
158	1.38	1.23	1.23	1.29	1.36	.43	1.23	1.27
168	1.36	-----	-----	-----	-----	-----	-----	-----
173	1.27	-----	1.23	1.29	1.29	.37	1.23	1.27
176	1.20	1.13	-----	-----	.85	-----	-----	-----



Booster cross section - station 100



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	4.35	1.00	2.08	2.05	3.13	2.21	4.11	1.74
10	2.95	.22	1.05	.71	2.14	.80	2.77	.76
20	-.45	-.54	-.18	-.29	.31	-.38	.54	-.31

TABLE VI

NORMALIZED FIRST BENDING MODE SHAPE FOR BOOSTER 25 PERCENT FULL

[Frequency, 13.6 cps; amplitude, 0.8G peak-to-peak at station 385.5]

Force input:
Shaker 1 at station 24, 15 vector lb

Damping at station 386:
When $x_0(G) = 0.658$, $g = 0.052$

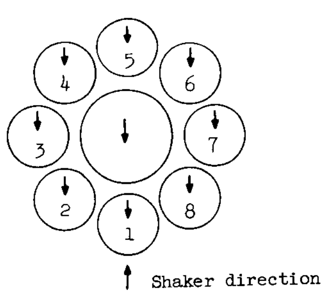
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	285	0.04	184	-0.59
375	.83	282	.05	180	-.60
365	.82	275	-.05	176	-.68
355	.67	265	-.12	164	-.66
346	.57	255	-.15	144	-.55
341	.53	245	-.20	113	-.43
335	.52	235	-.28	84	-.21
325	.41	225	-.34	54	.06
315	.32	215	-.40	35	.22
306	.23	207	-.46	29	.25
304	.21	205	-.49	24	.28
295	.10	194	-.60		

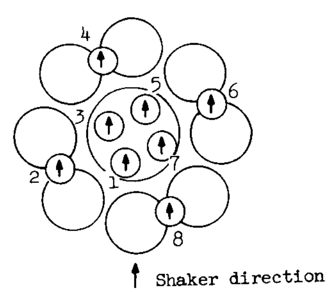
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	0.22	0.22	0.23	0.21	0.27	0.19	0.21	0.21
58	.09	.11	----	.08	.08	.09	.20	.14
78	----	----	----	-.10	----	-.09	----	----
98	-.20	-.19	----	-.26	-.23	-.25	-.18	-.35
118	-.37	-.34	-.61	-.39	-.32	-.38	-.33	-.48
138	-.54	-.48	-.67	-.62	-.45	-.56	-.51	-.61
158	-.62	-.67	-.71	-.67	-.67	-.67	-.64	-.70
173	-.73	-.75	-.74	-.78	-.75	-.74	-.73	-.83



Booster cross section - station 100



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	0.56	0.60	0.58	0.62	0.68	0.78	0.61	0.59
10	.43	.46	.56	.47	.39	.54	.48	.48
20	.34	.35	.34	.35	.32	.34	.34	.35

TABLE VII

NORMALIZED SECOND BENDING MODE SHAPE FOR BOOSTER 25 PERCENT FULL

[Frequency, 44.6 cps; amplitude, 0.30G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 15 vector lb

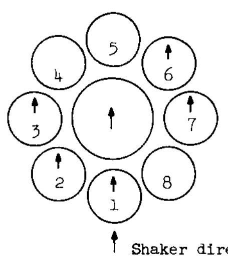
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	295	0.00	194	0.79
385	1.16	285	.13	184	.81
375	.98	282	.11	180	.97
365	.89	275	.38	176	1.17
355	.76	265	.37	164	1.09
346	.64	255	.89	144	1.18
341	.48	245	1.27	113	1.04
335	.48	235	1.17	84	.52
325	.29	225	1.24	54	-.17
315	.14	215	1.49	35	-.60
306	0	207	-.17	29	-.79
305	0	205	1.33	24	-.92

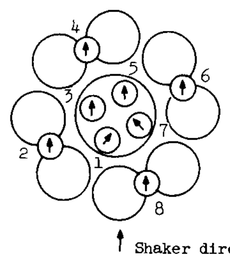
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	-0.71	-0.55	-0.73	-0.56	-0.73	-0.76	-----	---
58	-----	-----	-.18	-----	-----	-----	-0.27	---
78	.62	1.14	.76	-----	.74	.73	.43	---
98	1.04	-----	1.36	-----	-----	1.26	-----	---
118	1.45	2.28	1.66	-----	-----	-----	1.63	---
138	1.81	2.33	-----	-----	-----	-----	2.07	---
158	1.39	-----	1.60	-----	-----	-----	2.67	---
173	1.47	-----	1.82	1.72	-----	-----	2.37	---



Booster cross section - station 100



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	2.24	1.11	0.89	1.06	1.50	1.06	1.52	0.88
10	1.92	.33	.50	.56	1.03	.39	.83	.33
20	.39	-.28	-.11	-.17	.14	.17	----	-.15

(d) Second-stage ballast tank

Station	Deflection	Station	Deflection
195	-0.42	235	-1.21
205	-.59	245	-1.27
215	-.67	255	-1.11
225	-.90		

TABLE VIII

NORMALIZED FIRST BENDING MODE SHAPE FOR BOOSTER 48 PERCENT FULL

[Frequency, 13.0 cps; amplitude, 0.57G peak-to-peak at station 386]

Force input (shakers in phase):
Shaker 1 at station 24, 2.95 vector lb
Shaker 2 at station 345, 5.8 vector lb

Damping at station 386:
When $x_o(G) = 0.43$, $g = 0.032$
When $x_o(G) = 0.178$, $g = 0.017$

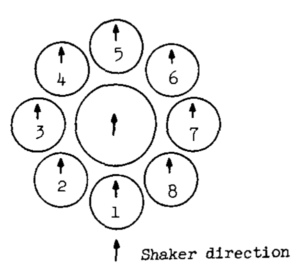
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	295	0.09	205	-0.53
380	.89	290	.05	200	-.62
375	.86	285	0	195	-.69
370	.78	282	0	184	-.65
365	.73	280	-.02	180	-.63
360	.69	275	-.07	179	-.65
355	.66	270	-.14	176	-.67
350	.60	265	-.15	173	-.70
345	.58	260	-.14	164	-.67
341	.53	255	-.16	144	-.55
340	.55	250	-.19	113	-.36
335	.53	245	-.23	84	-.21
330	.49	240	-.29	54	.10
325	.40	235	-.33	37	.24
320	.37	230	-.38	35	.32
315	.33	225	-.45	30	.39
310	.24	220	-.45	29	.38
306	.21	215	-.47	23	.38
305	.24	210	-.51	22	.47
300	.11	207	-.48	21	.40

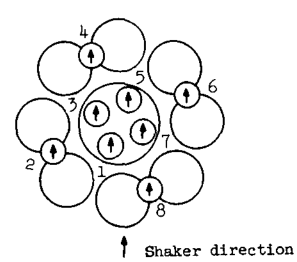
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(a) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	0.28	0.22	0.22	0.24	0.21	0.18	0.24	0.24
48	.20	.15	.18	.15	.13	.14	.18	.14
58	.09	.08	.14	.08	.09	.08	.13	.06
68	----	-.04	.12	----	-.18	-.03	.09	----
78	-.10	-.09	.08	-.10	-.36	-.08	.03	-.08
88	-.13	-.15	----	-.15	-.45	-.15	-.06	-.15
98	-.22	-.24	-.06	-.22	-.48	-.22	-.13	-.20
108	-.29	-.28	-.09	-.28	-.42	-.27	-.19	-.29
118	-.36	-.37	-.18	-.37	-.30	-.37	-.26	-.37
128	-.41	-.41	-.28	-.41	-.29	-.41	-.33	-.42
138	-.51	-.50	-.43	-.51	-.38	-.49	-.42	-.51
148	-.57	-.52	-.52	-.41	-.45	-.51	-.45	-.51
158	-.62	-.62	-.61	-.60	-.57	-.59	-.55	-.62
168	-.74	-.68	-.66	-.65	-.68	-.60	-.60	-.62
173	-.78	-.73	-.74	-.68	-.68	-.65	-.68	-.68



Booster cross section - station 180



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	0.71	0.76	0.76	0.71	0.68	0.73	0.73	0.73
10	.54	.57	.64	.66	.59	.57	.64	.59
20	.42	.45	.47	.54	.45	.47	.50	.45

TABLE IX

NORMALIZED FIRST CLUSTER MODE SHAPE FOR BOOSTER 48 PERCENT FULL

[Frequency, 26.0 cps; amplitude, 0.3G peak-to-peak at station 386]

Force input (shakers out of phase):
Shaker 1 at station 24, 5.8 vector lb
Shaker 2 at station 345, 4.45 vector lb

Damping at station 164:
When $x_o(G) = 0.078$, $g = 0.023$
When $x_o(G) = 0.032$, $g = 0.011$

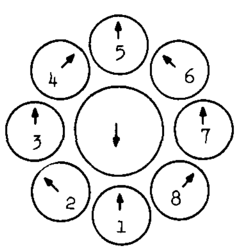
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	320	0.29	210	-0.38
380	.72	315	.29	207	-.66
375	.76	310	.24	205	-.43
370	.67	306	0	200	-.48
365	.57	305	.19	195	-.57
360	.53	300	.10	188	-.43
355	.53	290	-.14	184	-.57
350	.48	285	-.19	180	-.53
345	.53	282	-.09	179	-.62
341	.48	275	-.19	164	-.53
340	.53	265	-.19	144	-.54
335	.48	260	-.19	113	-.51
330	.33	240	-.24	84	-.49
325	.33	225	-.29	54	-.56

[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

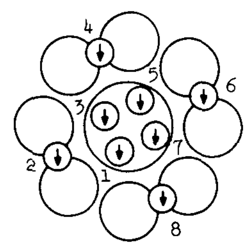
(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	-0.50	-0.60	-0.40	-0.20	-0.40	0.30	-0.40	-0.15
48	-.50	.60	-.50	.60	-.30	.50	-.30	.55
58	-----	.80	.60	1.10	.65	.70	.60	1.40
68	.80	1.30	1.10	1.40	1.50	1.00	.70	2.10
78	1.10	1.90	1.10	1.50	2.10	1.20	.90	3.30
88	1.30	2.00	1.00	1.60	1.80	1.40	.40	2.90
98	1.30	2.10	1.00	1.70	1.20	1.20	.50	2.50
108	1.20	1.90	.70	1.60	.90	1.00	.70	2.20
118	1.10	1.80	.80	1.60	.60	.70	.80	2.00
128	.70	1.40	.60	1.30	.50	.70	.60	1.50
138	-----	1.20	.70	1.20	.60	.60	.60	1.10
148	-----	.60	-----	.80	-----	----	-----	.80
158	-.30	.30	-.40	.50	-.30	----	-.30	.20
168	-.70	-.20	-.45	.50	-.40	----	-.50	-.70
173	-.60	-.70	-.60	.70	-.50	----	-.60	-.50



Shaker direction

Booster cross section - station 80



Shaker direction

Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	-3.50	-3.25	-3.63	-3.50	-3.38	-3.50	-5.00	-3.50
10	-2.63	-2.00	-2.88	-2.50	-2.63	-2.50	-3.38	-2.50
20	-1.37	-1.37	-1.62	-1.50	-1.37	-1.37	-1.50	-1.88

TABLE X

NORMALIZED SECOND CLUSTER MODE SHAPE FOR BOOSTER 48 PERCENT FULL

[Frequency, 33.9 cps; amplitude, 0.06G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 18 vector lb

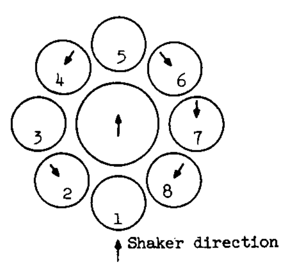
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	315	0.22	250	-----
380	.85	310	.17	245	-----
375	.85	306	0	207	-0.59
370	.78	304	.07	180	0
365	.74	300	-.07	176	.36
360	.67	295	-.11	173	.35
355	.67	290	-.14	164	.51
350	.57	285	-.13	144	1.16
346	.50	282	0	113	2.66
341	.48	280	0	84	2.78
340	.48	270	----	54	1.48
335	.65	265	----	35	.03
330	.44	259	----	29	.03
325	.33	255	----	24	.17
320	.26				

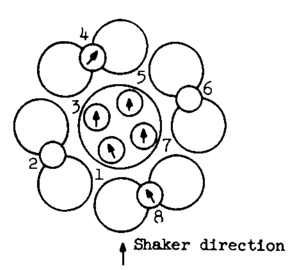
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	---	-0.27	---	0.10	---	-----	0.16	-0.17
48	---	-.24	---	----	---	-----	-.16	0
58	---	-.21	---	-.17	---	-0.34	-.18	-.10
68	---	-.30	---	----	---	-----	-.34	-.27
78	---	-.45	---	-.37	---	-.75	-.57	-.37
88	---	-.25	---	----	---	-----	-.64	-.53
98	---	-.41	---	-.49	---	-.75	-.65	-.63
108	---	-.31	---	----	---	-----	-.74	-.71
118	---	-.31	---	-.48	---	-.67	-.65	-.71
128	---	-.17	---	----	---	-----	-.50	-.70
138	---	-.23	---	-.35	---	-.41	-.41	-.60
148	---	-.14	---	----	---	-----	-.27	-.37
158	---	-.11	---	-.22	---	-.14	-.16	-.17
168	---	-.09	---	----	---	-----	-.19	0
174	---	-----	---	----	---	-----	----	.12
176	---	.12	---	----	---	-----	.15	.13



Booster cross section - station 100



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	-0.29	---	2.28	0.43	0.76	---	1.94	1.79
10	-.18	---	1.12	.20	.32	---	1.26	.78
20	-.06	---	.35	.18	.19	---	.36	.16

TABLE XI

NORMALIZED SECOND BENDING MODE SHAPE FOR BOOSTER 48 PERCENT FULL

[Frequency, 38.9 cps; amplitude, 0.14G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 24 vector lb

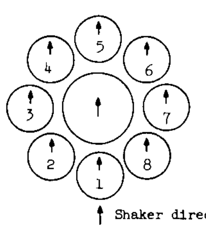
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	290	-0.04	215	0.87
385	1.07	285	-.04	212	.94
380	.98	282	.04	210	.87
375	.92	280	.10	207	-.21
370	.87	275	.22	205	.77
365	.79	270	.25	202	.73
360	.72	267	.31	200	.58
355	.66	265	.17	195	.38
350	.60	262	.22	188	.49
346	.55	259	.29	184	.34
341	.47	255	.46	180	0
340	.49	253	.56	179	.45
335	.45	250	.60	176	.68
330	.38	245	.64	173	.68
325	.30	242	.69	164	.66
320	.23	240	.67	144	.91
315	.16	235	.62	113	1.19
310	.08	232	.69	84	.89
306	.06	231	.61	54	.28
305	0	225	.69	35	-.72
300	-.06	222	.84	29	-.94
295	-.06	220	.80	24	-.89

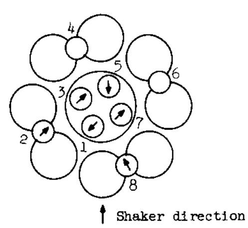
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	-0.67	-0.67	-0.73	-0.61	-0.67	-0.73	-0.79	-0.73
48	-.48	-.48	-.55	-.45	-.48	-.52	-.61	-.48
58	-.18	-.30	-.33	-.12	-.24	-.30	-.42	-.36
68	-.24	-.24	0	.39	0	-.24	-.27	-.33
78	.58	.24	.24	.79	.30	.42	.24	.33
88	.79	.27	.39	.91	.45	.42	.36	.52
98	.88	.36	.39	.88	.58	.48	.45	.61
108	.85	.55	.39	.85	.61	.55	.58	.67
118	.85	.67	.48	.85	.64	.61	.61	.67
128	.79	.70	.48	.85	.73	.64	.61	.67
138	.79	.67	.52	.85	.79	.61	.67	.67
148	.82	.67	.55	.79	.73	.61	.76	.64
158	.76	.67	.58	.79	.70	.61	.73	.64
168	.79	.70	.73	.67	.79	.58	.76	.61
173	.79	.67	.64	.67	.73	.61	.76	.61
176	.67	-----	-----	-----	.61	-----	-----	-----



Booster cross section - station 120



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	-10.96	5.23	14.47	---	-11.79	---	9.93	17.22
10	-7.03	2.13	7.78	---	-6.18	---	5.99	11.58
20	-1.64	-.97	-2.84	---	-2.52	---	1.33	.64

(d) Second-stage ballast tank

Station	Deflection	Station	Deflection
267	-0.72	232	-0.78
262	-.62	222	-.70
253	-.79	212	-.77
242	-.80	202	-.96

TABLE XII

NORMALIZED THIRD BENDING MODE SHAPE FOR BOOSTER 48 PERCENT FULL

[Frequency, 47.8 cps; amplitude, 0.28G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 24 vector lb

Damping at station 180:
When $x_o(G) = 0.065$, $g = 0.017$

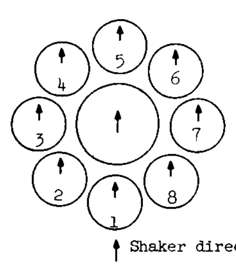
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	305	-0.11	215	1.15
385	1.00	300	-.14	210	1.19
380	.93	295	-.11	207	.08
375	.85	290	-.06	205	1.12
370	.81	285	.07	200	.97
365	.74	282	.08	194	.78
360	.66	280	.09	184	.82
355	.64	275	.29	179	1.04
350	.58	270	.36	176	1.08
346	.48	265	.29	173	1.13
341	.45	259	.43	164	1.19
340	.41	255	.66	144	1.14
335	.36	250	.82	113	.74
330	.26	245	.93	84	.20
325	.17	240	.90	54	-.30
320	.11	235	.69	35	-.30
315	.06	231	.86	29	-.26
310	-.10	225	.97	24	-.16
306	-.09	220	1.12		

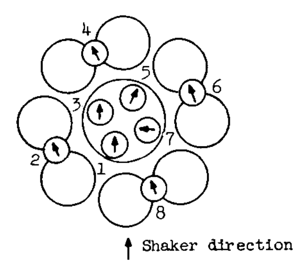
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	-0.44	-0.44	-0.44	-0.46	-0.49	-0.44	-0.41	-0.40
48	-.42	-.36	-.44	-.38	-.42	-.36	-.46	-.36
58	-.33	-.33	-.31	-.35	-.33	-.26	-.39	-.22
68	.51	-.24	-.15	-.44	-.31	-.16	-.09	.36
78	.78	-.24	.22	-.40	.36	.40	.32	.87
88	.82	.46	.40	.29	.51	.44	.47	.80
98	.75	.64	.67	.51	.67	.60	.78	.71
108	.73	.84	1.06	.75	.82	.73	.97	.77
118	.93	1.04	1.31	.93	.91	.93	1.26	1.02
128	1.11	1.20	1.42	1.13	1.22	1.09	1.31	1.15
138	1.29	1.35	1.59	1.31	1.31	1.26	1.49	1.29
148	1.40	1.39	1.62	1.37	1.49	1.26	1.60	1.44
158	1.44	1.48	1.46	1.46	1.44	1.42	1.49	1.42
168	1.49	1.48	1.55	1.44	1.53	1.44	1.60	1.40
173	1.44	1.49	1.44	1.46	1.46	1.44	1.42	1.49
176	1.37	-----	-----	-----	.84	-----	-----	-----



Booster cross-section - station 120



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	31.30	7.16	11.68	19.45	27.43	11.50	23.34	9.80
10	16.62	.80	6.16	6.16	19.12	2.09	15.56	3.19
20	2.57	-3.93	-.96	-2.89	2.09	-2.57	1.91	-1.59

TABLE XIII

NORMALIZED FOURTH BENDING MODE SHAPE FOR BOOSTER 48 PERCENT FULL

[Frequency, 60.0 cps; amplitude, 0.51G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 18 vector lb

Damping at station 386:
When $x_o(G) = 0.539$, $g = 0.011$
When $x_o(G) = 0.346$, $g = 0.007$

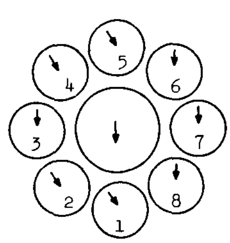
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
385	1.00	300	-0.34	220	-0.40
380	.93	295	-.32	215	-.41
375	.92	290	-.27	210	-.40
370	.88	285	-.27	207	.16
365	.80	282	-.21	205	-.33
360	.70	280	-.24	200	-.23
355	.61	275	-.25	184	.10
350	.57	270	-.24	180	.21
346	.43	265	-.23	164	.19
343	.39	259	-.30	163	.13
341	.30	255	-.33	144	.11
335	.22	250	-.35	143	.06
320	-.14	245	-.38	113	-.13
310	-.30	240	-.39	84	-.08
306	-.33	235	-.32	54	-.09
305	-.27	231	-.33	35	.11
304	-.32	225	-.36	24	.17

[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

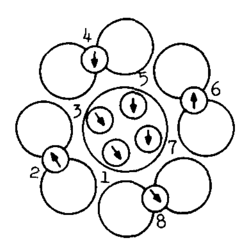
(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	0.05	0.04	----	0.04	0.03	-0.03	-0.02	0.04
48	.05	.04	----	.04	.03	-.03	-.01	.03
58	.05	.04	----	.03	----	-----	.02	.02
68	.02	.01	----	----	----	-----	.02	.02
78	-.06	-.06	----	----	----	-----	-----	-.02
88	-.11	-.08	----	-.05	----	-----	-.03	-.03
98	-.08	-.08	----	-.07	----	-----	-.03	-.03
108	-.05	-.06	----	-.07	----	-.03	-.04	-.02
118	-.03	-.04	----	-.05	----	-----	-.05	----
128	-.03	0	----	----	-.05	-----	-.07	.04
138	-.05	.03	----	----	-.07	-----	-.08	.05
148	-.08	.05	----	.05	-.08	-----	.08	.07
158	-.09	.08	0.07	.07	-.09		.08	.09
168	.13	.10	.10	.09	.12	.06	.09	.11
173	.14	.11	.09	.10	.11	.07	.07	.11
176	.14	----	----	----	-.07	-----	-----	----



Shaker direction

Booster cross section - station 100



Shaker direction

Engine motion - station 0

(c) Engines

Station	Normalized deflections for engine -							
	1	2	3	4	5	6	7	8
0	-0.12	0.03	-0.05	-0.03	-0.09	0.04	-0.08	-0.09
10	-.04	----	-.01	-----	-.03	----	-.03	-.03
20	.04	-.01	.03	.04	.02	-.02	.03	.06

TABLE XIV

NORMALIZED FIRST BENDING MODE SHAPE FOR BOOSTER 75 PERCENT FULL

[Frequency, 12.1 cps; amplitude, 0.85G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 15 vector lb

Damping at station 386:
When $x_o(G) = 0.204$, $g = 0.02$

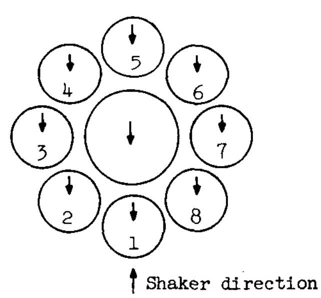
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	295	0.16	184	-0.52
385	1.02	285	.08	180	-.46
375	.87	265	-.10	176	-.60
365	.78	255	-.15	164	-.43
355	.70	245	-.21	144	-.44
346	.61	235	-.27	113	-.35
341	.54	225	-.33	84	-.16
335	.56	215	-.39	54	.07
325	.46	207	-.38	35	.31
315	.39	205	-.48	29	.35
306	.27	194	-.55	24	.38
304	.27				

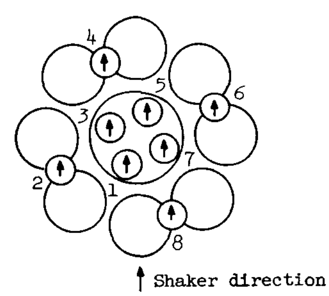
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	0.43	0.44	0.42	0.46	0.43	0.40	0.42	0.45
58	.33	.27	.28	.19	.31	.20	.26	.23
78	.19	.10	.05	----	.17	----	.07	.05
98	-.12	-.23	-.22	-.30	----	-.39	-.22	-.29
118	-.31	-.41	-.50	-.50	-.33	-.43	-.47	-.45
138	-.53	-.58	-.68	-.65	-.54	-.58	-.60	-.59
158	-.71	-.76	-.77	-.80	-.68	-.75	-.72	-.75
173	-.87	-.86	-.84	-.83	-.84	-.87	-.82	-.82



Booster cross section - station 120



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	0.62	0.72	0.81	0.90	0.65	0.59	0.87	1.01
10	.50	.62	.78	.68	.54	.56	.75	.51
20	.44	.44	.50	.45	.44	.44	.53	.44

TABLE XV

NORMALIZED FIRST CLUSTER MODE SHAPE FOR BOOSTER 75 PERCENT FULL

[Frequency, 20.8 cps; amplitude, 0.32G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 16 vector lb

Damping at station 207:
When $x_o(G) = 0.13$, $g = 0.025$
When $x_o(G) = 0.05$, $g = 0.015$

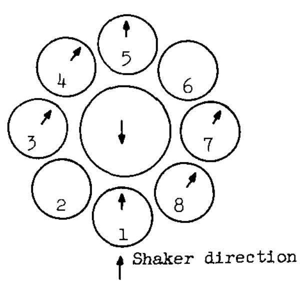
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	285	-0.10	184	-0.74
375	.83	275	-.11	180	-.44
365	.76	265	-.23	176	-.73
355	.63	255	-.23	164	-.76
346	.50	245	-.24	144	-1.03
341	.46	235	-.33	113	-1.05
335	.44	225	-.37	84	-1.10
325	.34	215	-.41	54	-.79
315	.26	207	-.61	35	-.70
306	.12	205	-.49	29	-.83
304	.10	194	-.63	24	-.95

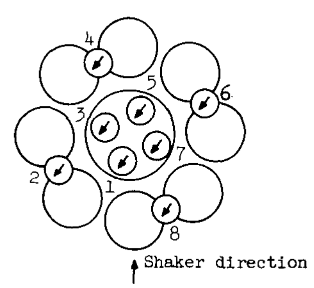
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	-0.41	---	-0.21	0.11	-0.44	---	-0.13	-0.12
58	-.15	---	.18	.57	-----	---	-----	.61
78	.44	---	.64	1.29	.56	---	-----	1.16
98	.70	---	.73	1.52	-----	---	.96	1.44
118	.53	---	.80	1.30	.79	---	-----	-----
138	.17	---	.43	.70	-----	---	-----	.58
158	-.33	---	-.20	.22	-.40	---	-.14	.07
173	-.54	---	-.27	.24	-.62	---	-.40	-.22



Booster cross section - station 100



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	-2.86	-2.86	-2.43	-3.81	-2.27	-3.38	-3.17	-2.91
10	-2.06	-2.17	-2.06	-2.64	-2.27	-2.43	-2.33	-2.33
20	-1.64	-1.53	-1.32	-1.69	-1.59	-1.59	-1.59	-1.59

TABLE XVI

NORMALIZED SECOND CLUSTER MODE SHAPE FOR BOOSTER 75 PERCENT FULL

[Frequency, 27.6 cps; amplitude, 0.40G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 15 vector lb

Damping at station 386:
When $x_o(G) = 0.34$, $g = 0.022$
When $x_o(G) = 0.175$, $g = 0.016$

(a) Main structure[a]

Station	Deflection	Station	Deflection
386	1.00	235	-0.07
385	.84	225	-.09
375	.85	215	-.12
365	.73	207	-.40
355	.62	205	-.16
346	.52	194	-.38
341	.46	184	-.34
335	.45	180	-.18
325	.33	178	-.09
315	.20	164	-.15
306	.11	144	.19
304	.08	113	.67
295	-.03	84	.73
285	-.06	54	.39
275	-.07	35	-.07
265	-.12	29	-.17
255	-.04	24	-.32
245	-.04		

[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

TABLE XVII

NORMALIZED SECOND BENDING MODE SHAPE FOR BOOSTER 75 PERCENT FULL

[Frequency, 36.9 cps; amplitude, 0.36G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 15 vector lb

Damping at station 207:
When $x_o(G) = 0.09$, $g = 0.039$
When $x_o(G) = 0.026$, $g = 0.019$

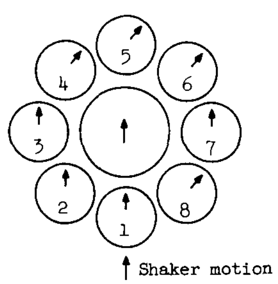
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	282	0	184	0.20
385	1.27	275	.13	180	.25
375	.97	265	.13	176	.53
365	.88	255	.34	164	.41
355	.71	245	.44	144	.55
346	.59	235	.41	113	.61
341	.47	225	.44	84	.29
335	.53	215	.59	54	-.22
325	.34	207	-.32	35	-.52
315	.20	205	.51	29	-.52
306	.26	194	.16	24	-.47

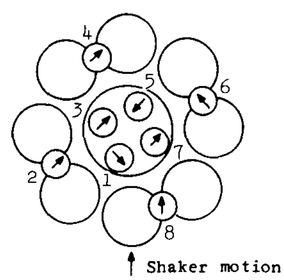
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	-0.62	-0.57	-0.55	-0.22	-0.49	-0.66	-0.85	-0.73
58	-.46	-.44	-.51	-.14	-.53	-.52	-.73	-.53
78	-----	-.16	-1.09	-----	-2.01	-----	-.27	-.26
98	.29	.31	.79	.20	2.53	.37	.62	.35
118	.53	.59	1.13	.25	1.82	.64	1.08	.73
138	.71	.63	1.19	.25	-----	.70	1.04	.70
158	.63	.60	.90	.15	.77	.56	1.01	.58
173	.55	.55	.61	.16	.58	.48	.72	.50



Booster cross section - station 120



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	-3.41	1.27	2.91	1.27	-1.59	2.47	3.01	4.66
10	-1.46	-.35	2.34	2.09	-.89	2.23	2.49	5.54
20	-.55	-.23	.36	-.44	-.40	.26	.42	-.83

TABLE XVIII

NORMALIZED OUTER FUEL TANK MODE SHAPE FOR BOOSTER FULL

[Frequency, 9.1 cps; amplitude, 0.08G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 21 vector lb

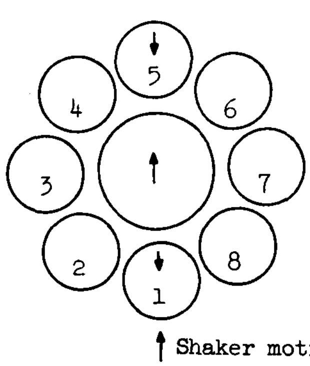
(a) Main structure[a]

Station	Deflection	Station	Deflection
386	1.00	164	0.39
341	.59	144	.61
306	.49	113	1.09
207	.35	84	1.76
180	.18		

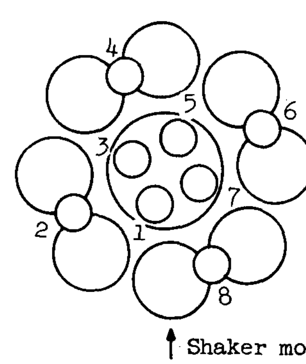
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -		Station	Normalized deflection for tank -	
	1	5		1	5
38	1.28	1.43	118	-11.60	-13.25
48	-1.13	-2.14	128	-11.21	-12.64
58	-4.00	-5.59	138	-7.92	-10.24
68	-7.96	-8.57	148	-6.24	-8.18
78	-9.66	-11.24	158	-3.87	-5.02
88	-11.60	-12.04	168	-1.67	-2.45
98	-11.98	-13.65	173	-.95	-1.38
108	-11.78	-14.45	176	-.52	------



Booster cross section - station 100



Engine motion - station 0
(no engines measured)

TABLE XIX

NORMALIZED FIRST BENDING MODE SHAPE FOR BOOSTER FULL

[Frequency, 10.5 cps; amplitude, 1.2G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 30 vector lb

Damping at station 386:
When $x_o(G) = 0.568$, $g = 0.033$
When $x_o(G) = 0.162$, $g = 0.025$

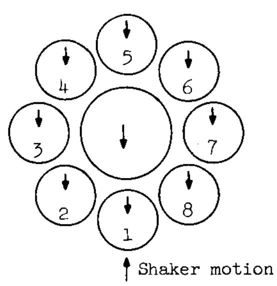
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	295	0.19	184	-0.44
385	.99	285	.12	180	-.28
375	.86	275	.06	176	-.53
365	.76	265	-.03	164	-.48
355	.69	255	-.05	144	-.44
346	.58	245	-.11	113	-.30
341	.56	235	-.17	84	-.06
335	.57	225	-.23	54	.22
325	.47	215	-.28	35	.42
315	.38	207	-.29	29	.48
306	.28	205	-.35	24	.51
304	.28	194	-.47		

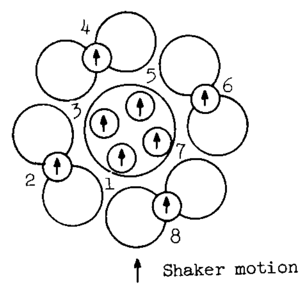
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	0.38	0.35	0.36	0.35	0.38	0.37	0.35	0.39
58	.28	.21	.24	.17	.29	.21	.21	.19
78	.19	.07	.08	----	.21	----	----	----
98	.06	-.13	-.13	-.17	.09	-.12	-.15	-.15
118	-.12	-.28	-.29	-.31	-.09	-.30	-.29	-.30
138	-.26	-.39	-.39	-.42	-.24	-.37	-.39	-.39
158	-.41	-.44	-.44	-.42	-.39	-.43	-.44	-.43
173	-.51	-.49	-.53	-.46	-.48	-.50	-.47	-.47



Booster cross section - station 120



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	0.71	1.01	0.81	0.76	0.74	0.99	0.80	0.69
10	.59	.62	.61	.58	.45	.65	.61	.48
20	.51	.52	.52	.45	.38	.53	.50	.40

TABLE XX

NORMALIZED FIRST CLUSTER MODE SHAPE FOR BOOSTER FULL

[Frequency 18.4 cps; amplitude, 0.15G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 15 vector lb

Damping at station 144:
When $x_o(G) = 0.149$, $g = 0.017$

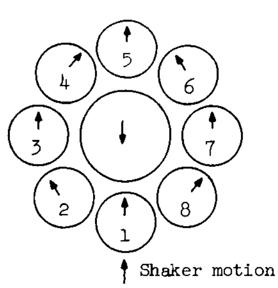
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	285	-0.10	184	-0.77
375	.85	275	-.16	180	-.77
365	.74	265	-.23	176	-.78
355	.63	255	-.27	164	-.88
346	.55	245	-.36	144	-.98
341	.46	235	-.42	113	-1.08
335	.44	225	-.48	84	-.85
325	.34	215	-.53	54	-.53
315	.25	207	-.64	35	-.28
306	.14	205	-.63	29	-.33
304	.12	194	-.72	24	-.47

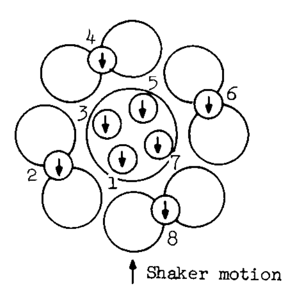
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	-0.15	-0.12	0.11	0.12	-0.12	0.13	0.11	0.11
58	-----	.29	----	.49	.16	.37	.23	.39
78	-----	.67	----	.96	-----	.58	.66	.75
98	.55	.91	.76	1.31	.51	.61	----	.91
118	.42	-----	----	1.10	-----	.55	----	----
138	-----	-----	----	.65	-----	----	----	----
158	-.53	-.36	-.29	----	-.51	-.32	-.34	-.34
173	-.74	-.67	-.34	-.27	-.75	-.66	-.59	-.63



Booster cross section - station 100



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	-0.84	-0.93	-0.64	-0.95	-0.71	-0.80	-0.69	-0.97
10	-.66	-.69	-.53	-.84	-.62	-.71	-.58	-.78
20	-.51	-.44	-.40	-.47	-.49	-.47	-.44	-.51

TABLE XXI

NORMALIZED MODE SHAPE ASSOCIATED WITH THIRD VEHICLE RESPONSE FOR BOOSTER FULL

[Frequency 24.0 cps; amplitude, 0.22G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 15 vector lb

Damping at station 386:
When $x_o(G) = 0.098$, $g = 0.014$

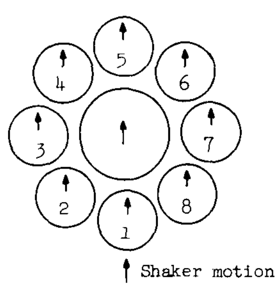
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	295	-0.04	185	-0.56
385	1.05	285	-.07	180	-.45
375	.89	275	-.11	176	-.52
365	.77	265	-.17	164	-.40
355	.67	255	-.13	144	-.05
346	.52	245	-.13	113	.48
341	.44	235	-.22	84	.65
335	.48	225	-.24	54	.05
325	.46	215	-.27	35	.25
315	.24	207	-.51	29	-.14
306	.11	205	-.35	24	-.36
304	.10	194	-.55		

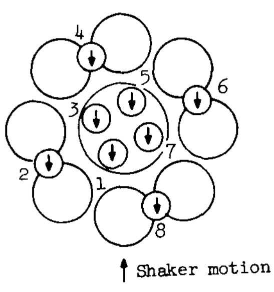
[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

(b) Booster outer tanks

Station	Normalized deflection for tank -							
	1	2	3	4	5	6	7	8
38	0.21	0.27	0.17	0.18	0.23	0.20	0.18	0.15
58	.49	.37	.35	.30	.47	.23	.32	.23
78	.67	.37	.30	.41	.63	.41	.24	.18
98	.79	.23	-.20	.27	.55	.17	-.24	----
118	.67	-.21	-.63	-.14	.52	-.20	-.49	-.40
138	-.24	-.50	-.66	-.56	-.44	-.38	-.61	-.55
158	-.59	-.69	-.66	-.64	-.69	-.53	-.58	-.61
173	-.63	-.69	-.55	-.63	-.85	-.64	-.50	-.61



Booster cross section - station 80



Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	-2.87	-4.46	-3.18	-3.84	-4.35	-3.66	-3.08	-3.61
10	-1.58	-2.60	-1.96	-2.14	-1.89	-1.58	-1.86	-2.00
20	-1.02	-1.23	-1.09	-1.02	-1.05	-.95	-.98	-.98

TABLE XXII

NORMALIZED MODE SHAPE ASSOCIATED WITH FOURTH VEHICLE RESPONSE FOR BOOSTER FULL

[Frequency, 30.6 cps; amplitude, 0.96G peak-to-peak at station 386]

Force input:
Shaker 1 at station 24, 15 vector lb

Damping at station 386:
When $x_o(G) = 0.403$, $g = 0.010$

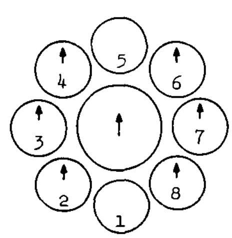
(a) Main structure[a]

Station	Deflection	Station	Deflection	Station	Deflection
386	1.00	285	-0.04	194	-0.20
375	.81	275	-.02	184	-.14
365	.70	265	-.05	180	-.19
355	.61	250	.13	176	-.07
346	.47	245	.13	164	-.03
341	.47	240	.12	144	.13
335	.42	235	.06	113	.24
325	.31	225	.11	84	.21
315	.18	220	.15	54	.02
306	.10	215	.18	35	-.19
304	.06	210	.16	29	-.22
295	-.03	207	-.40	24	-.24
		200	-.20		

[a]Main structure includes third stage, second-stage outer shell, booster center lox tank, and barrel.

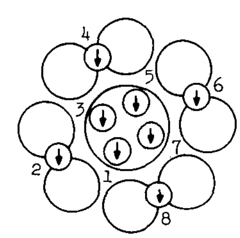
(b) Booster outer tanks

Station	Normalized deflection for tanks -							
	1	2	3	4	5	6	7	8
38	---	-0.25	-0.20	-0.22	---	-0.26	-0.25	-0.25
58	---	-.17	-.17	-.16	---	-.16	-.21	-.18
78	---	-----	-.13	-.08	---	-.06	-.14	-.06
98	---	-----	-----	.07	---	-----	-----	.08
118	---	.07	-----	-----	---	.13	.19	.15
138	---	.12	.14	.08	---	.10	-----	.12
158	---	.06	.07	.04	---	.04	.07	.04
173	---	-.05	-----	-.02	---	-.07	-.06	-.06



Shaker direction

Booster cross section - station 140



Shaker direction

Engine motion - station 0

(c) Engines

Station	Normalized deflection for engine -							
	1	2	3	4	5	6	7	8
0	-0.62	-2.40	-2.06	-0.88	-0.98	-1.73	-2.43	-1.14
10	-.38	-1.04	-.96	-.53	-.57	-.84	-1.10	-.67
20	-.27	-.35	-.38	-.26	-.30	-.41	-.45	-.34

(d) Second-stage inner tank

Station	Deflection	Station	Deflection	Station	Deflection
255	-0.56	235	-0.64	215	-0.71
250	-.62	230	-.63	210	-.79
245	-.61	225	-.63	205	-.88
240	-.61	220	-.63	200	-.89

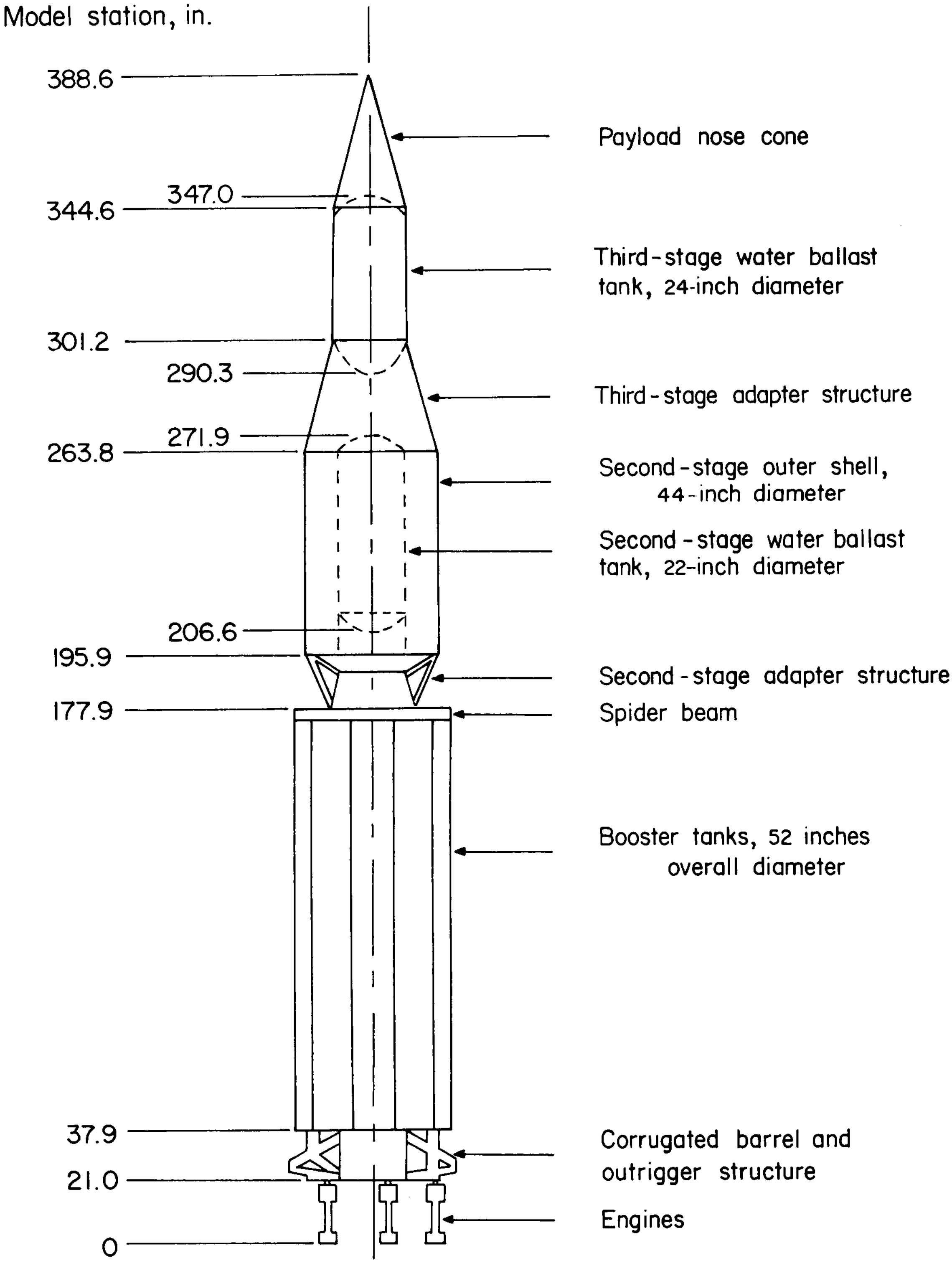
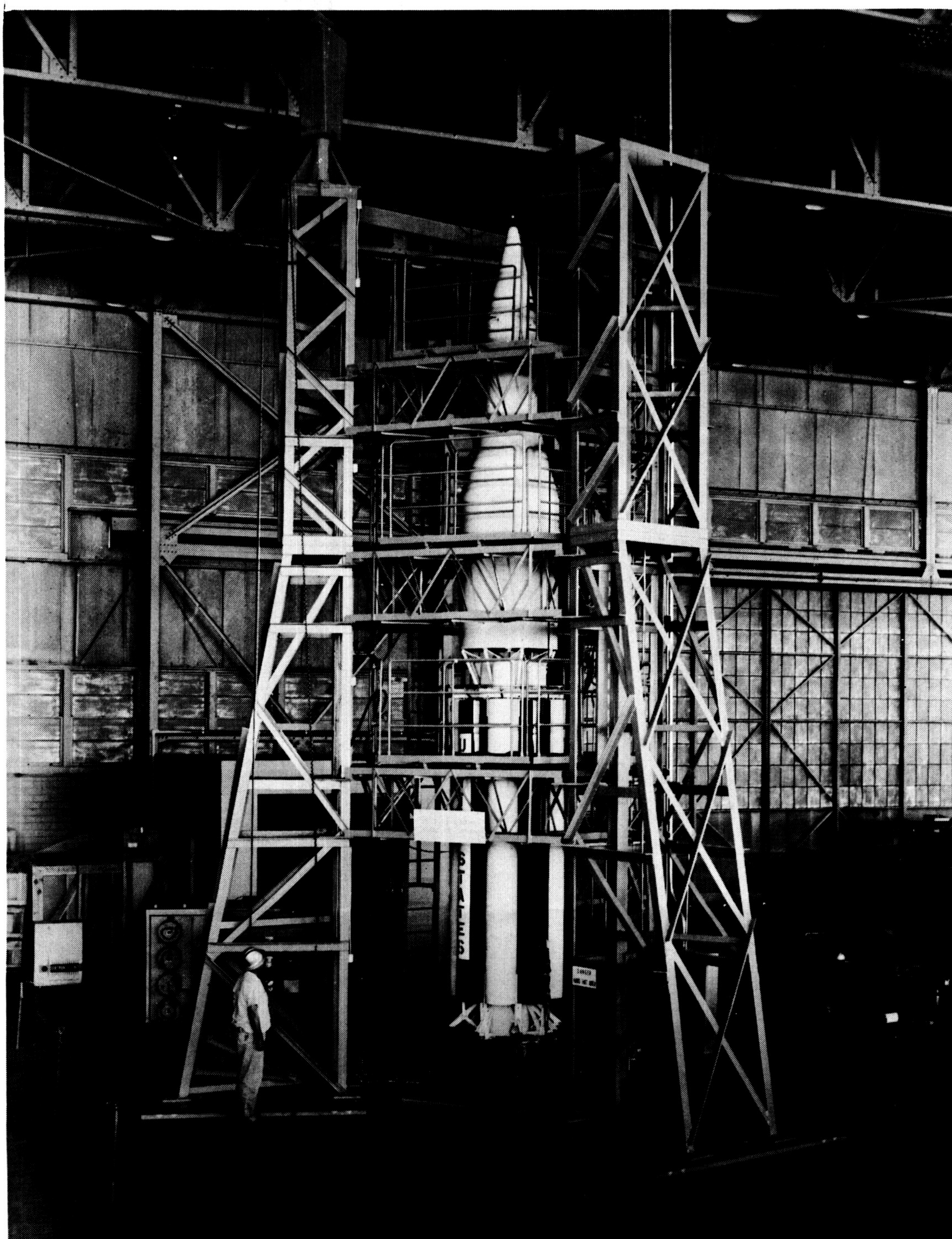


Figure 1.- General configuration, dimensions, and nomenclature of 1/5-scale model of Saturn SA-1.



L-61-4079
Figure 2.- The 1/5-scale Saturn model suspended in vibration testing tower.

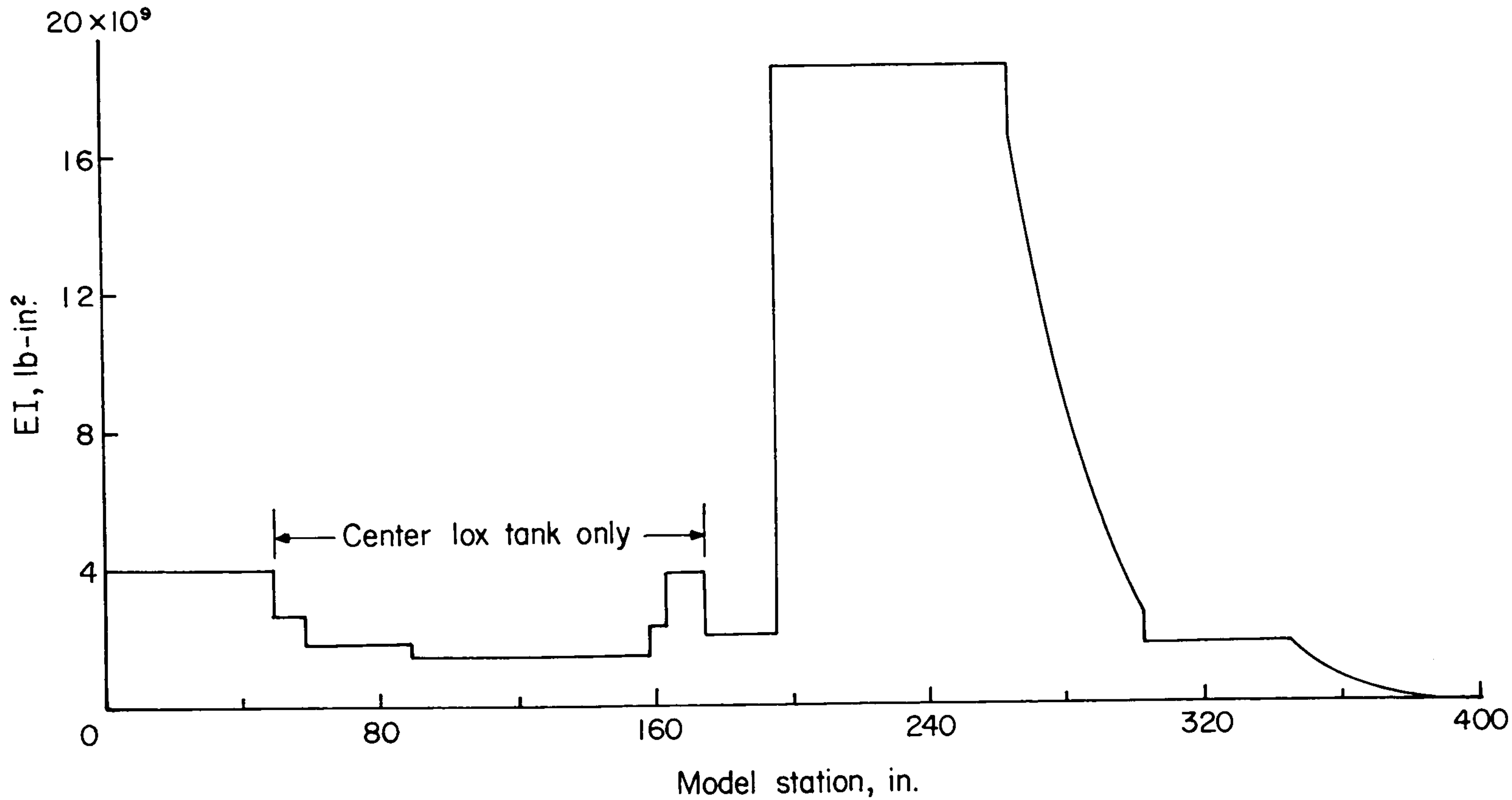


Figure 3.- Bending stiffness distribution of 1/5-scale Saturn model.

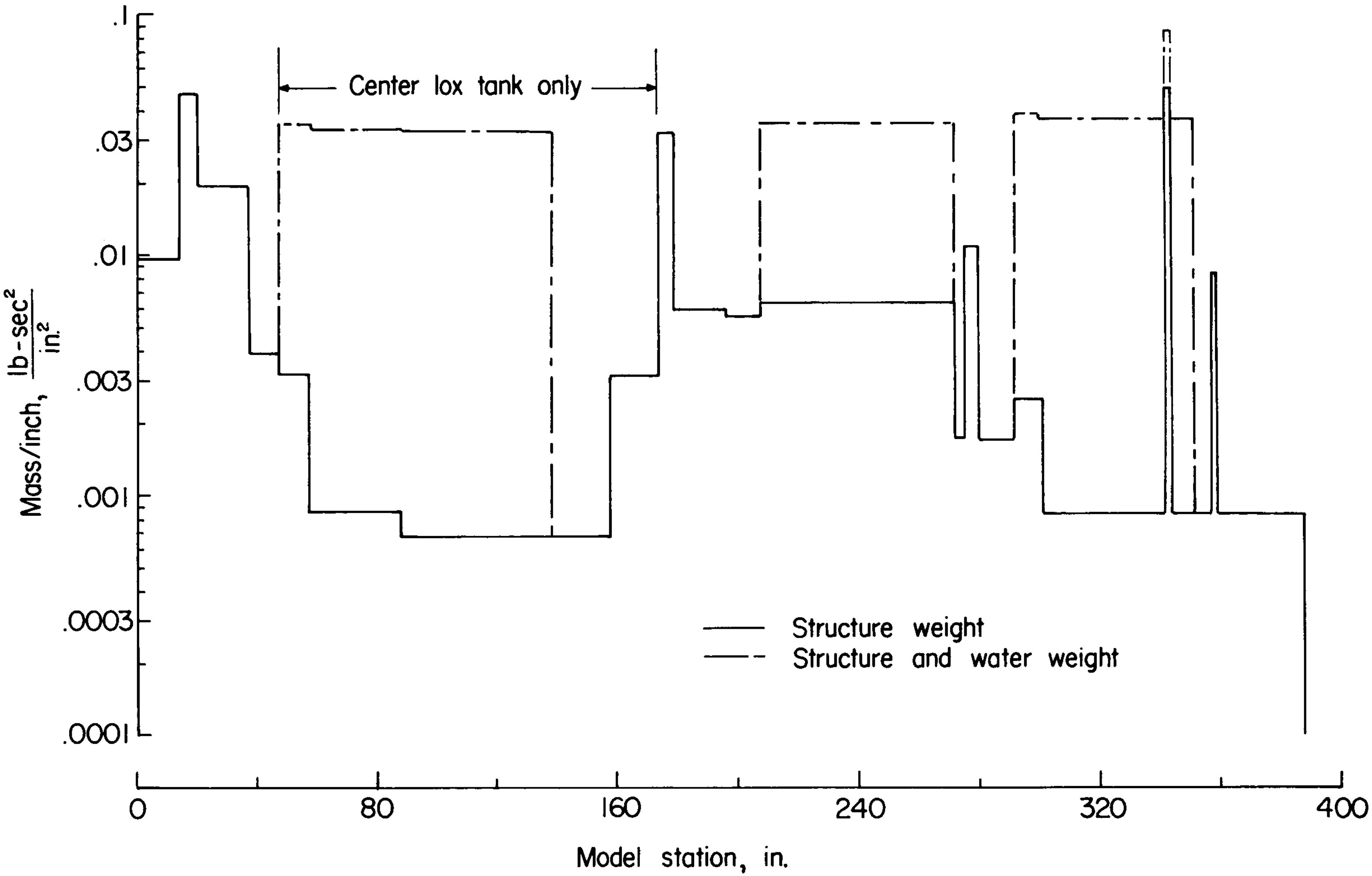


Figure 4.- Distribution of mass of 1/5-scale Saturn model.

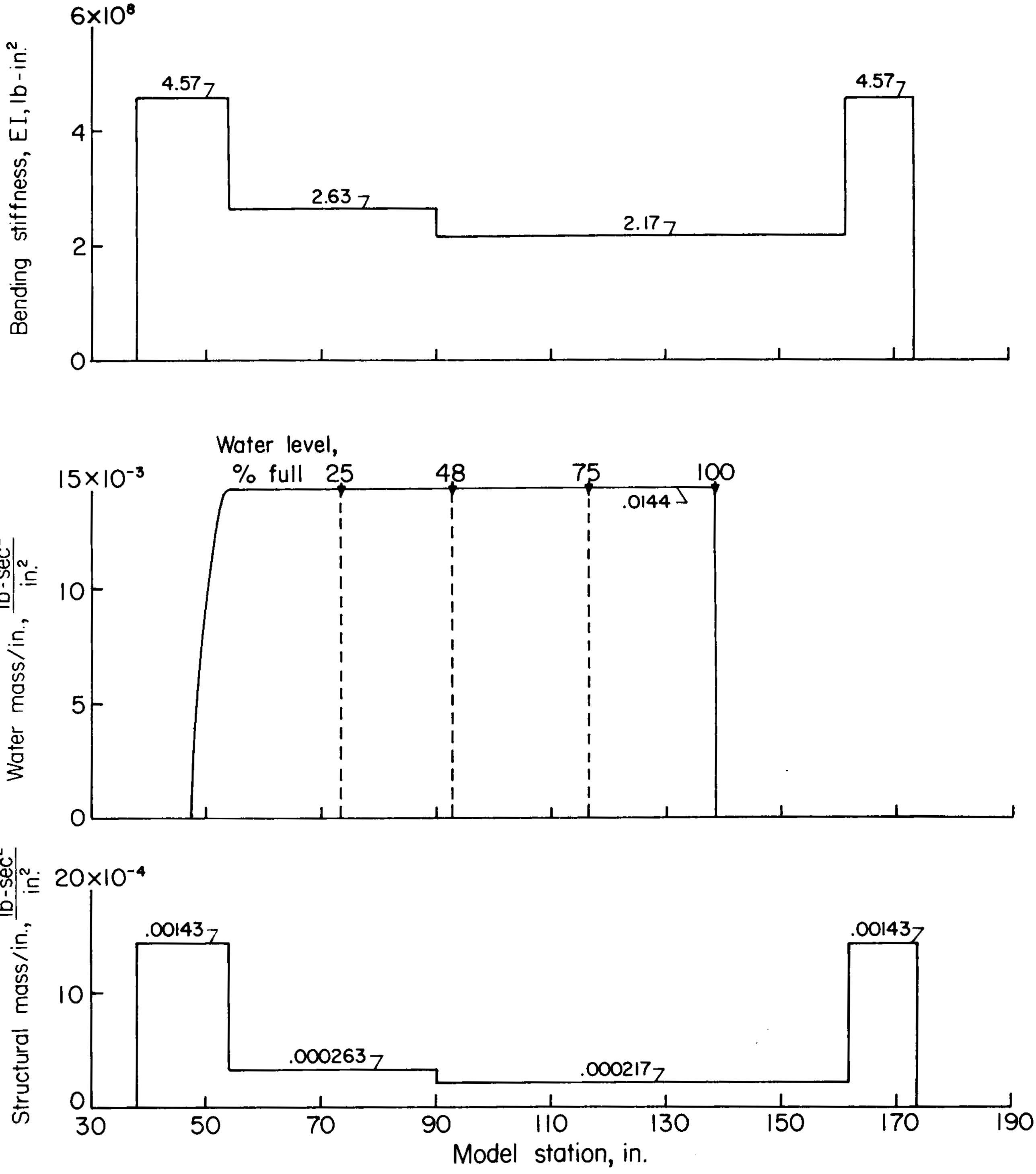


Figure 5.- Distribution of mass and bending stiffness of outer lox tank. 1/5-scale Saturn model; total length, 135.5 inches.

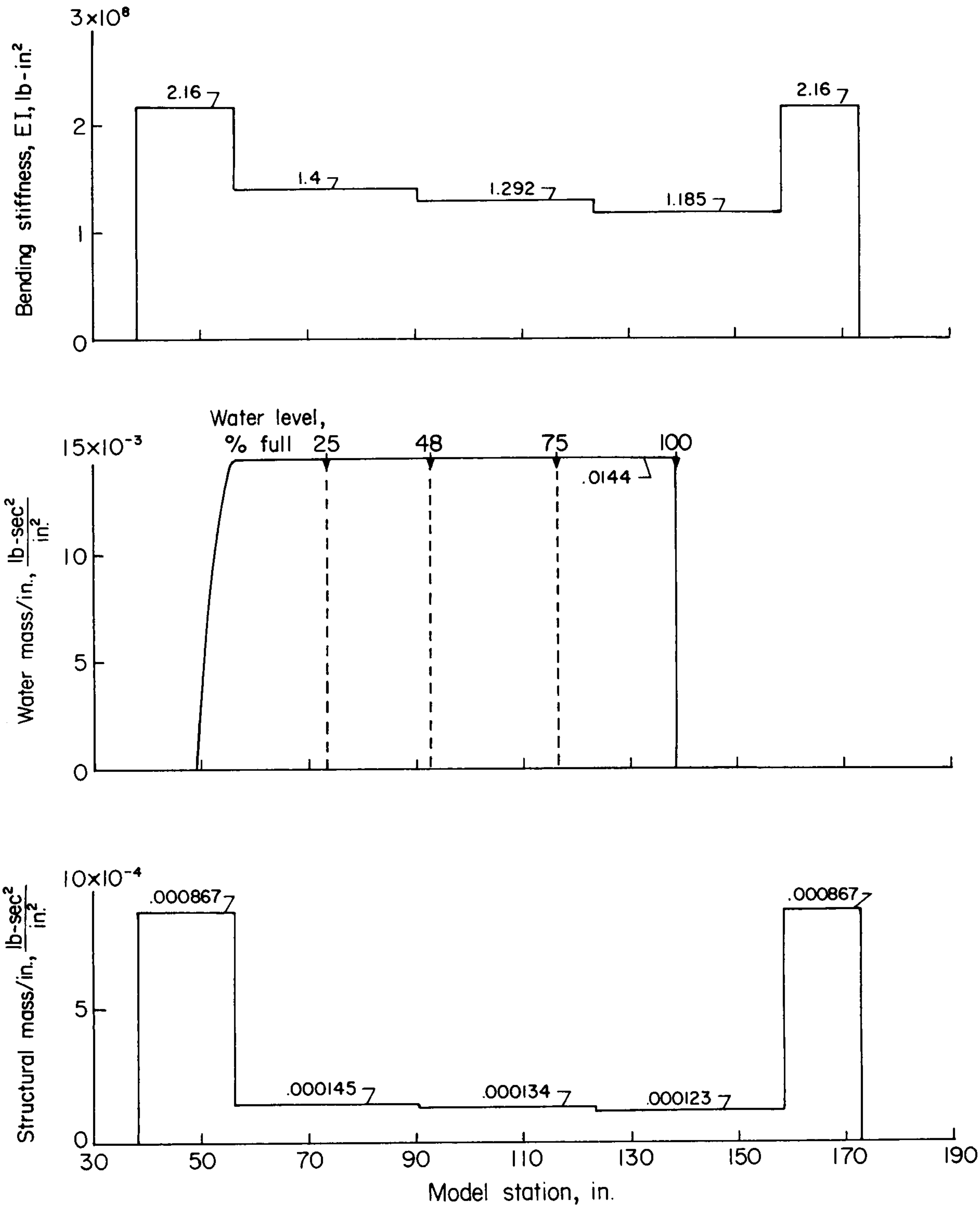


Figure 6.- Distribution of mass and bending stiffness of fuel tank. 1/5-scale Saturn model; total length, 134.78 inches.

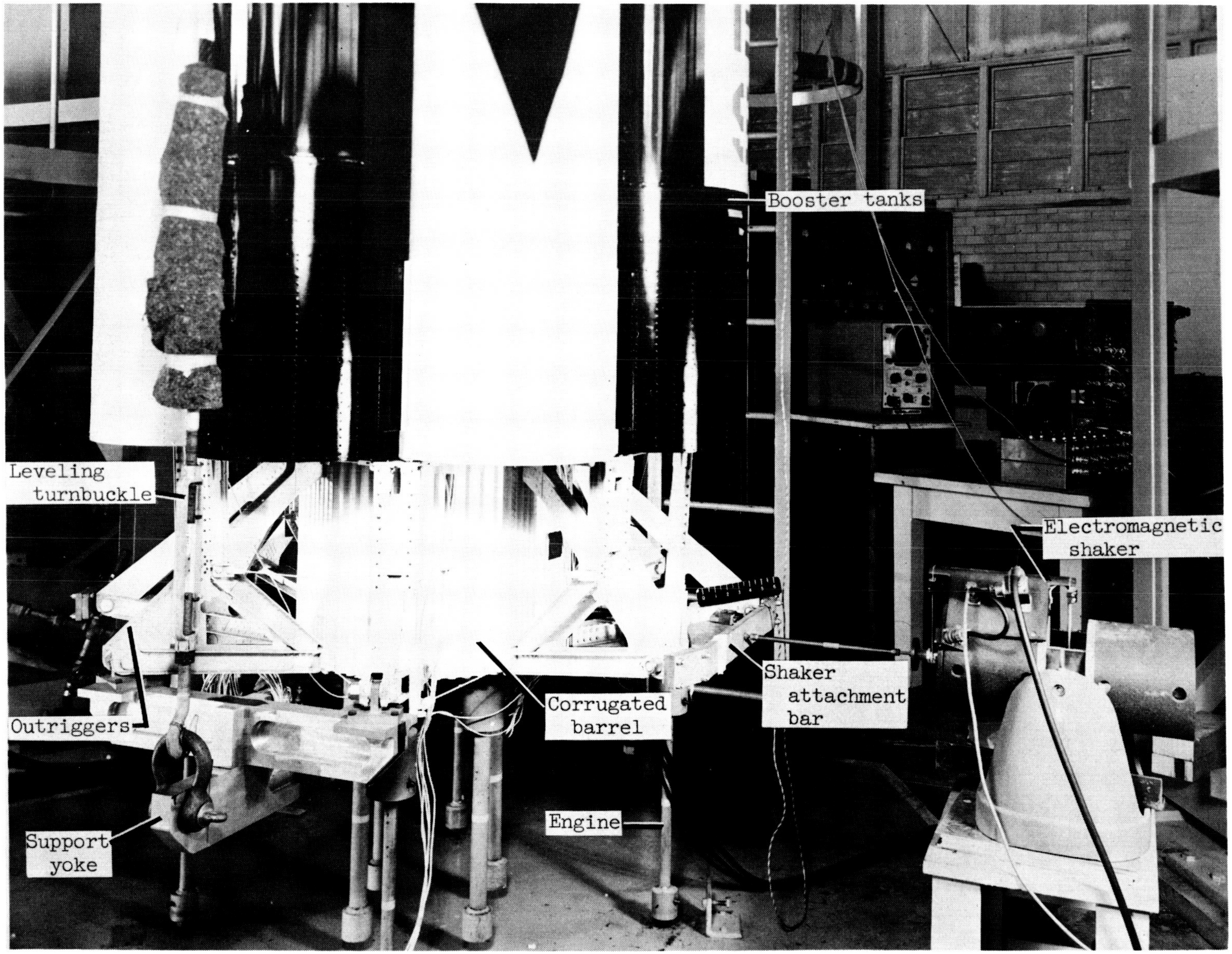


Figure 7.- Outrigger-barrel area of the 1/5-scale Saturn model. L-61-6583.1

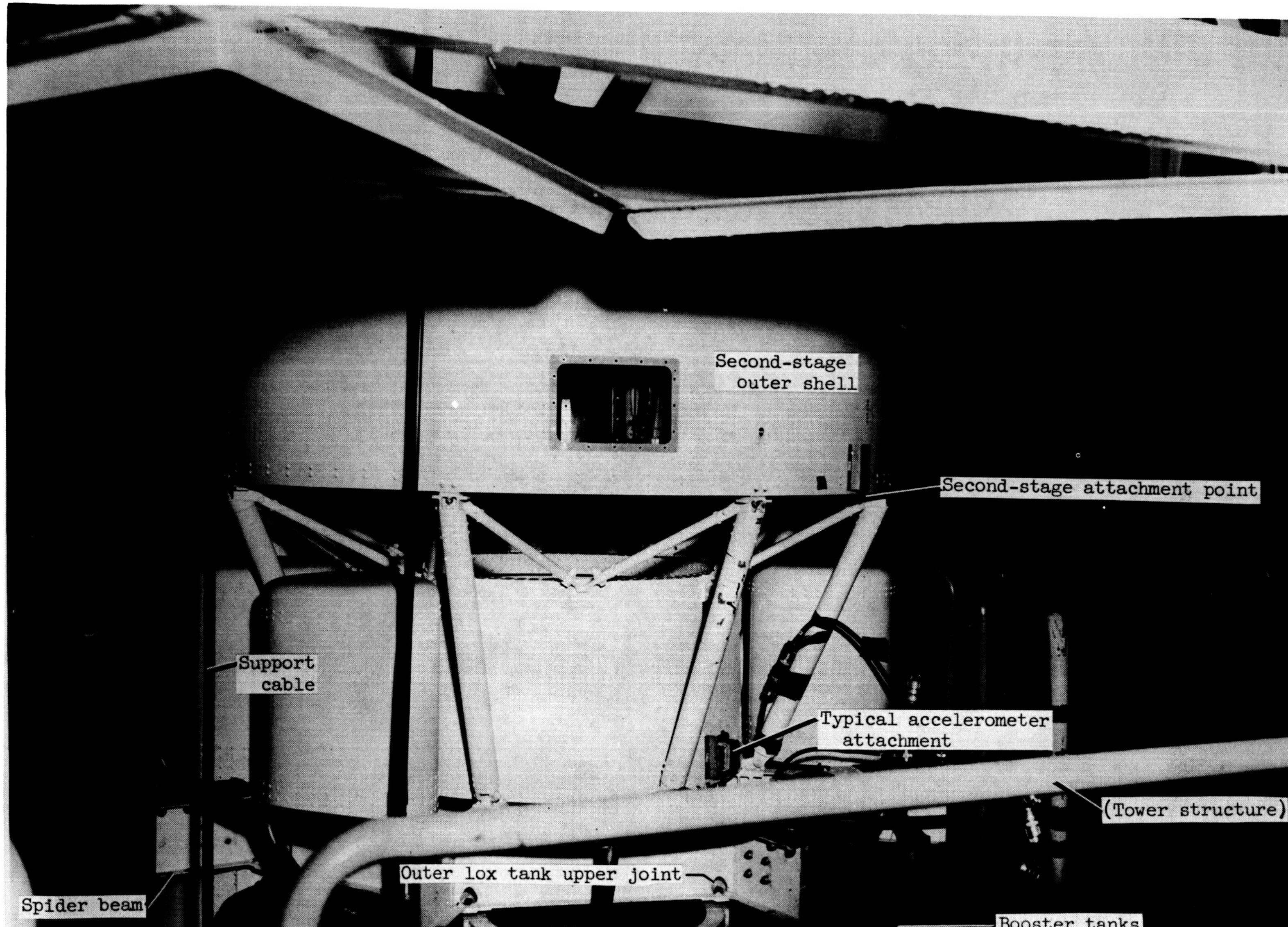


Figure 8.- Second-stage adapter area of 1/5-scale Saturn model. L-61-6110.1

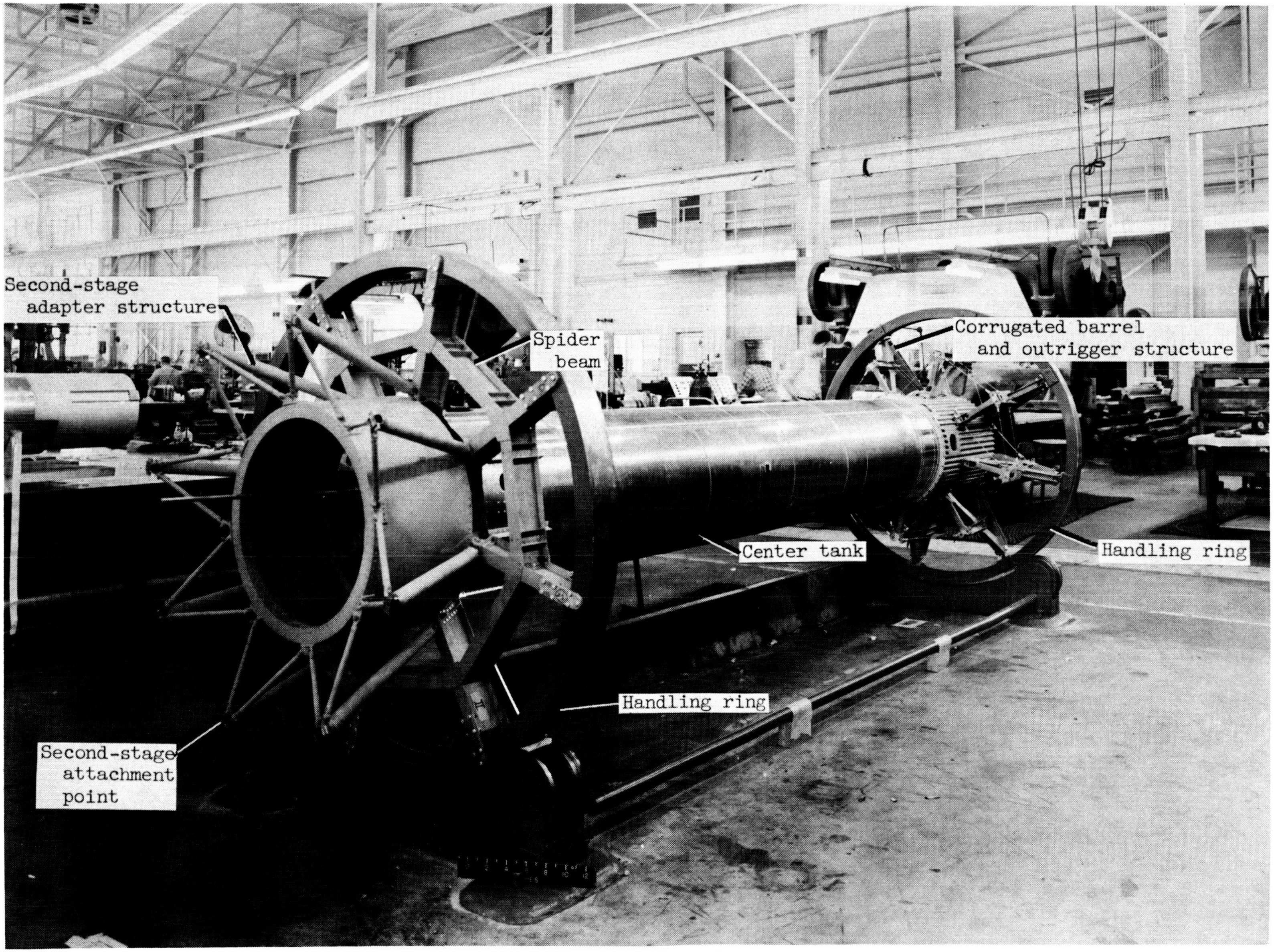


Figure 9.- Booster structure during assembly. L-61-1654.1

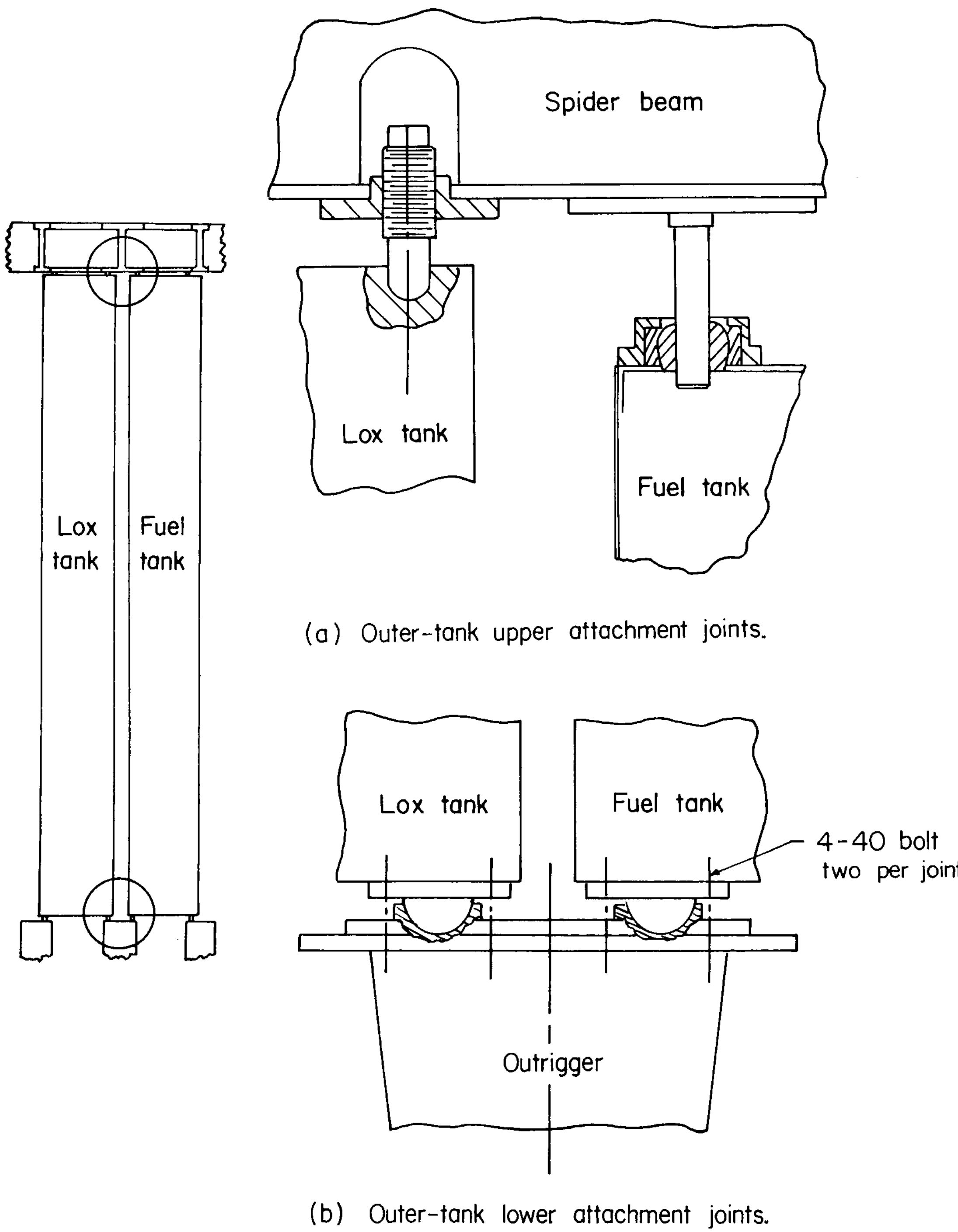


Figure 10.- Sketch of outer-tank attachment joints.

Figure 11.- Outer-tank upper attachment joints. L-61-3336.1

Figure 12.- End view of second stage of 1/5-scale Saturn model. L-61-2988.1

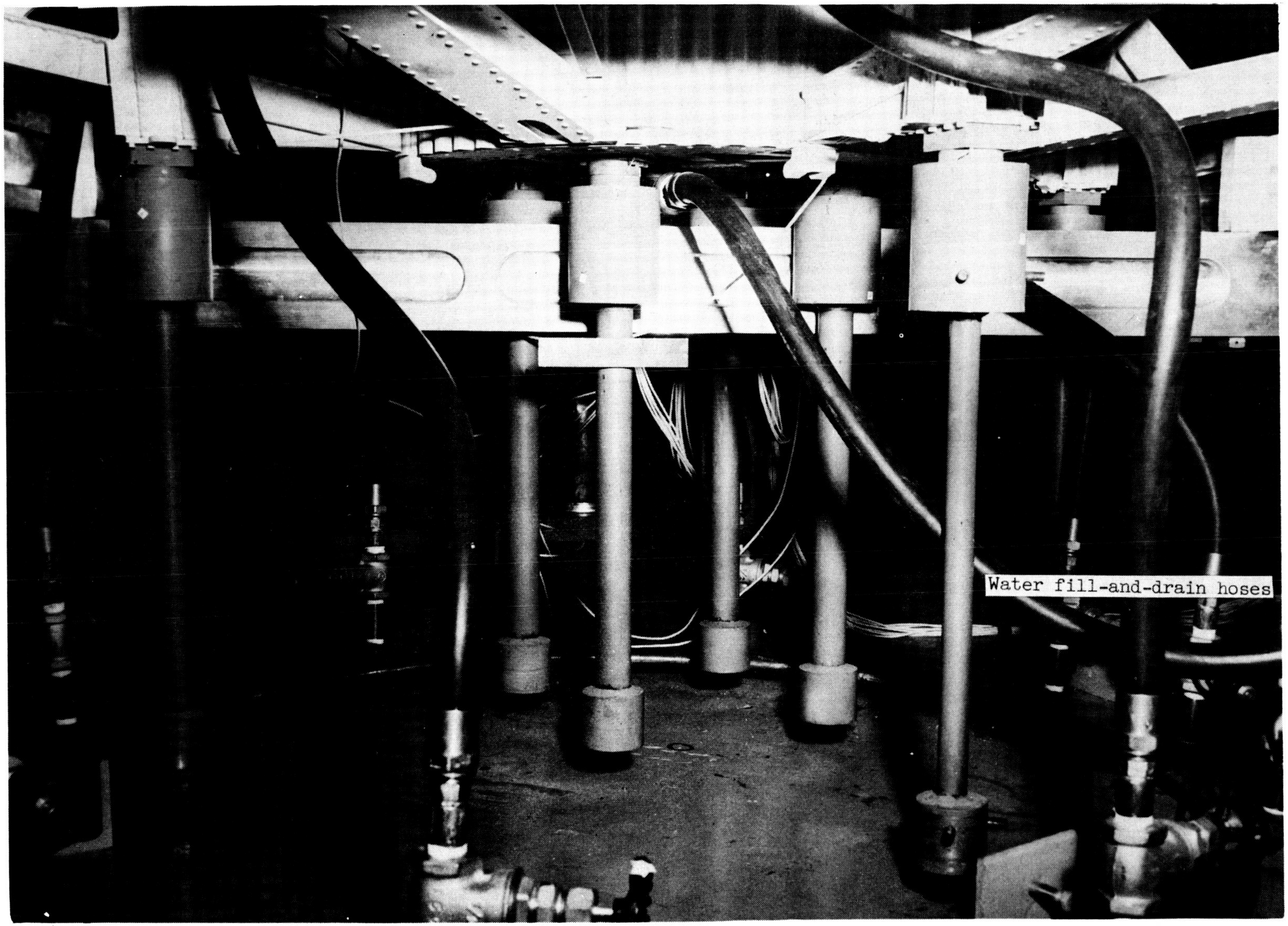


Figure 13.- Engine area of 1/5-scale Saturn model. L-61-3331.1

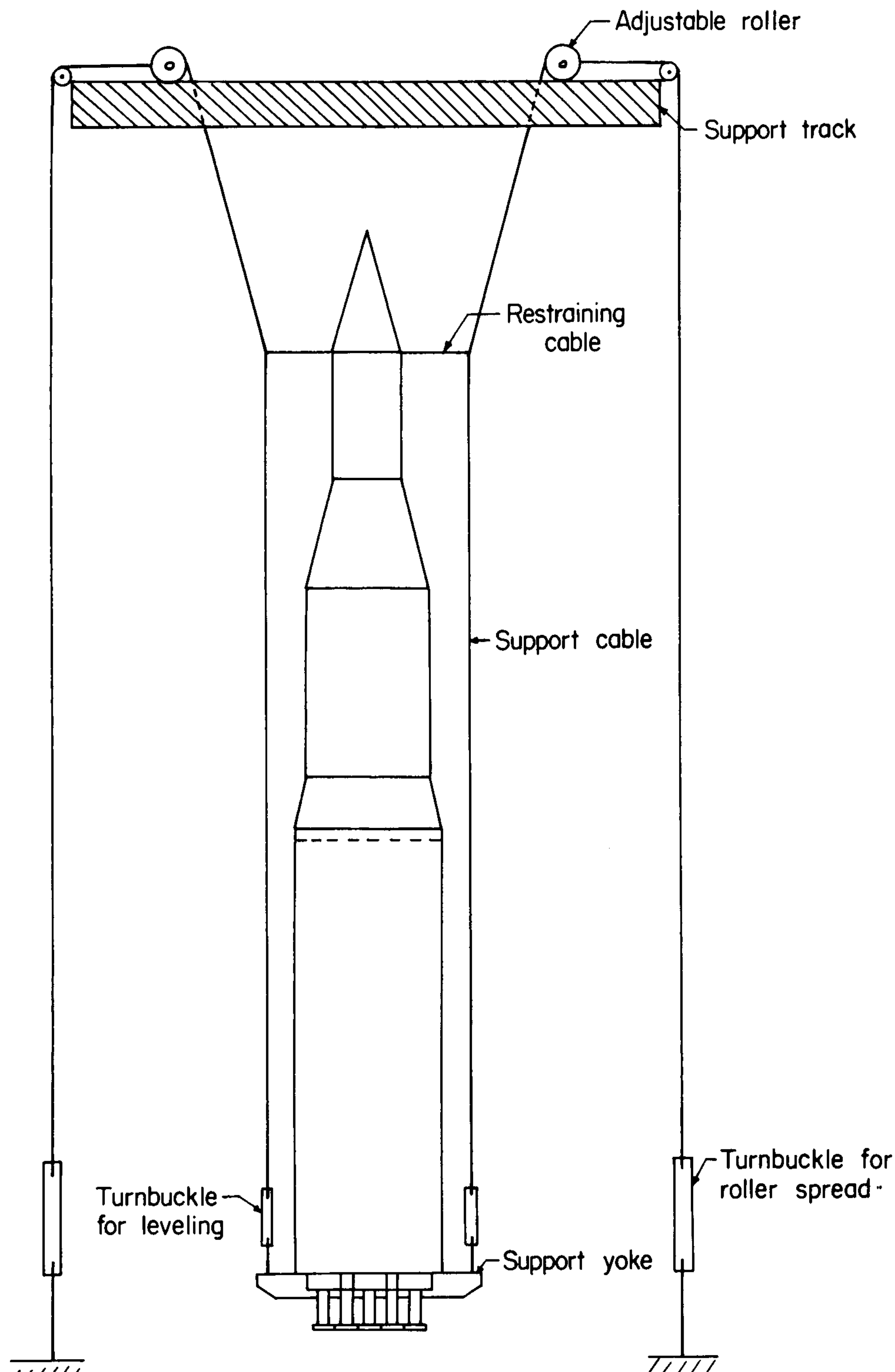


Figure 14.- Sketch of two-cable suspension system for 1/5-scale Saturn model.

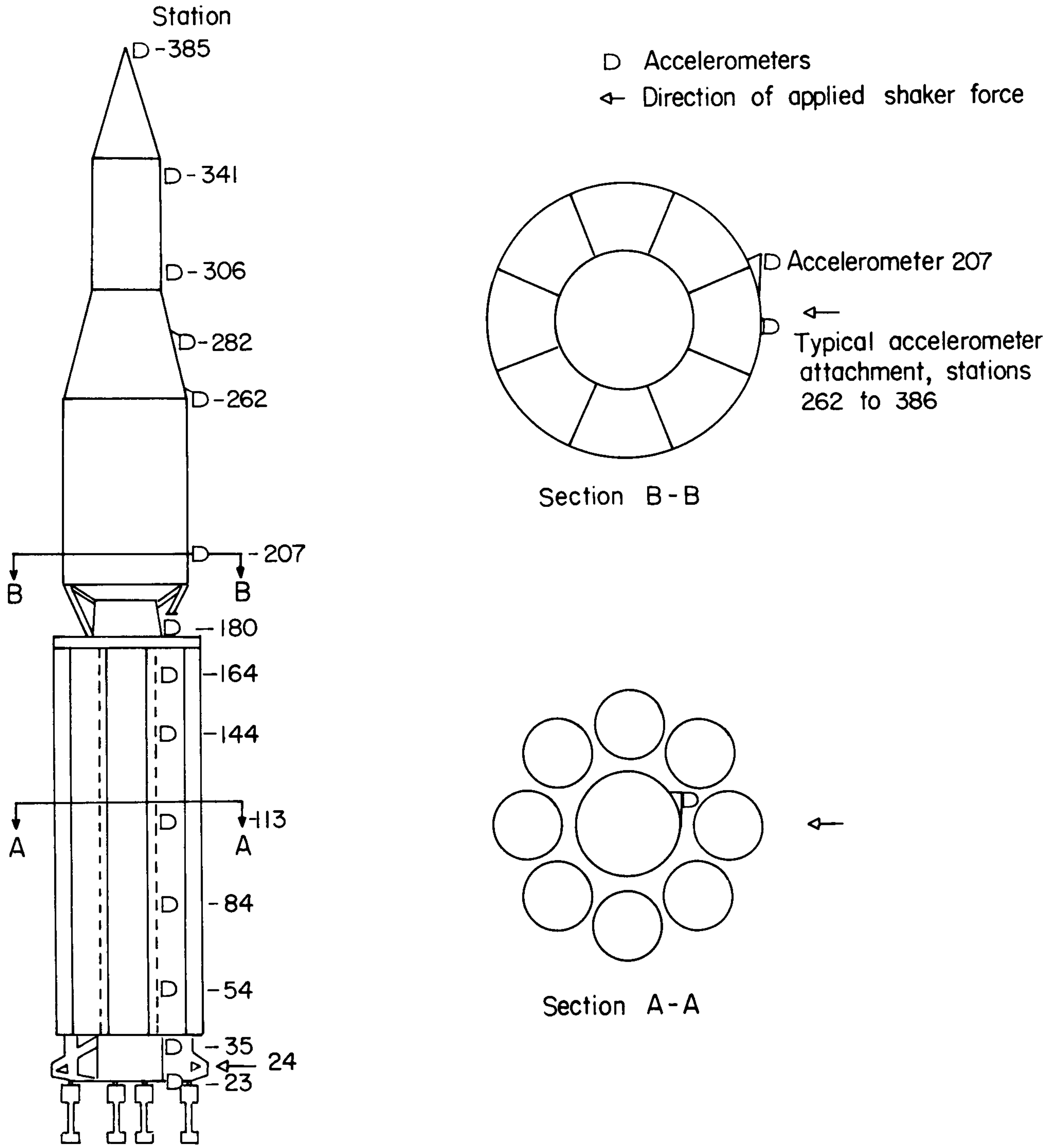


Figure 15.- Locations of fixed accelerometers on 1/5-scale Saturn model.

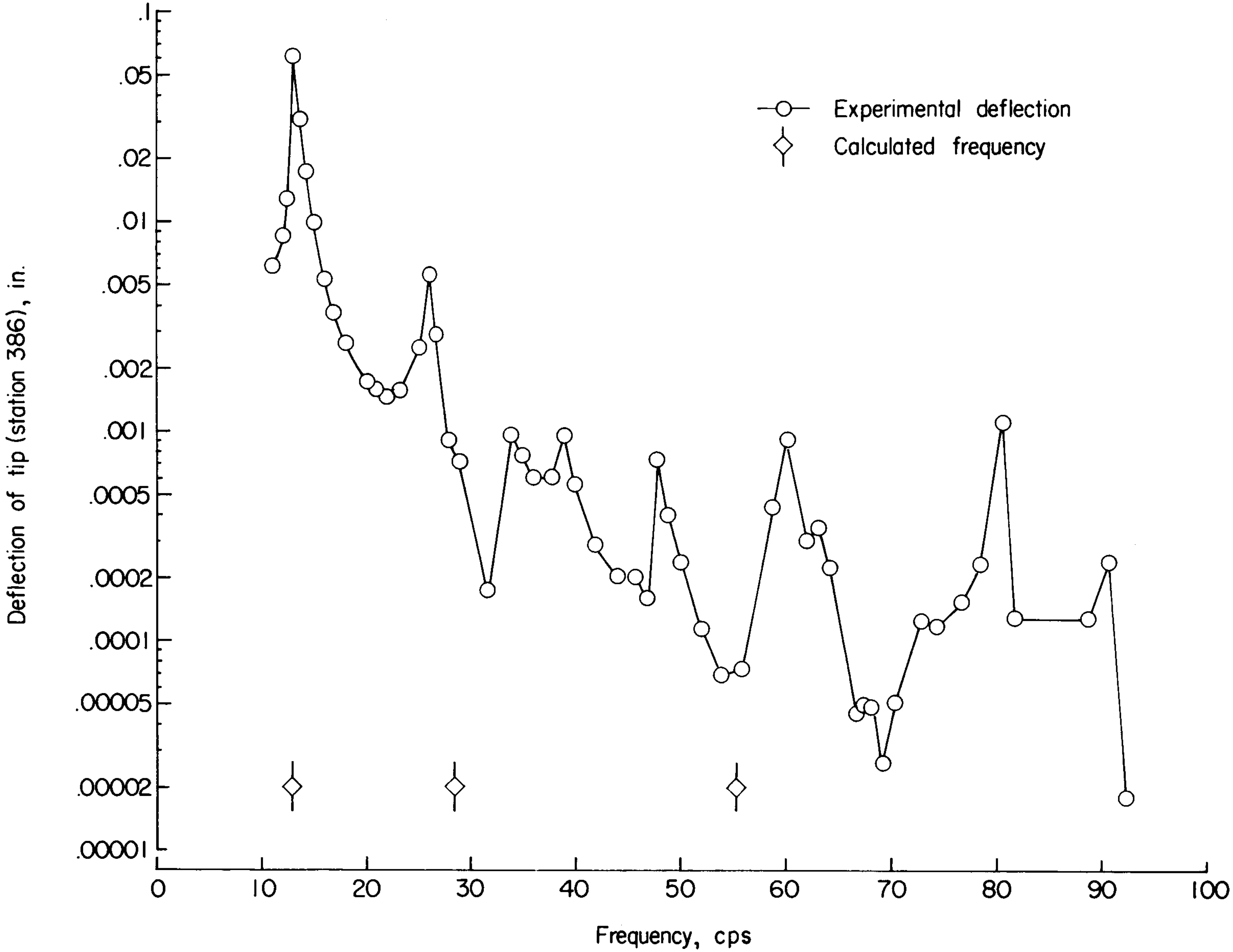


Figure 16.- Variation of tip deflection (station 386) with shaker frequency. Booster tanks 48 percent full; force, 22.5 vector lb when frequency < 65 cps and 13.5 vector lb when frequency > 65 cps.

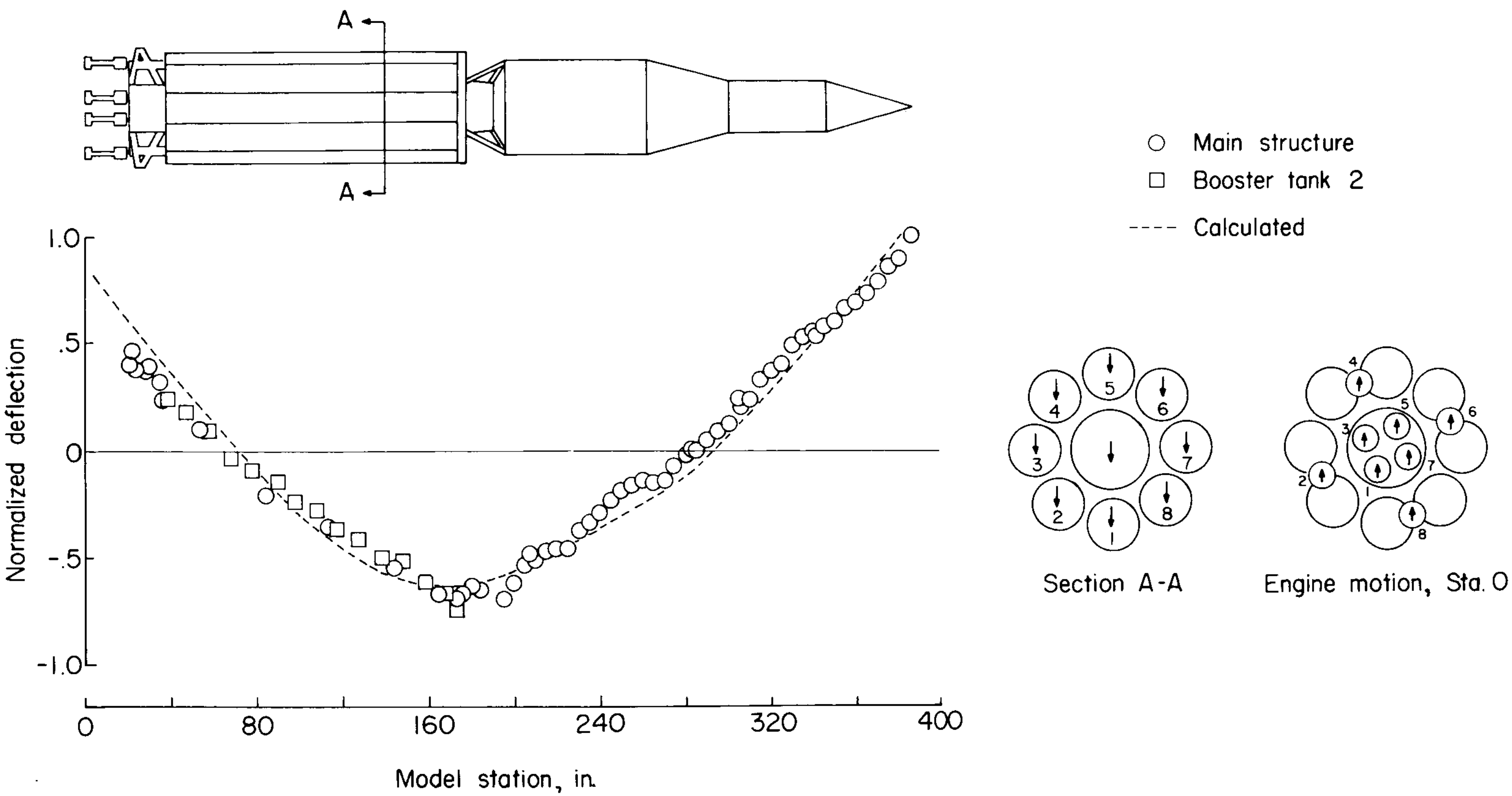


Figure 17.- First bending mode of 1/5-scale Saturn. Booster tanks 48 percent full; frequency, 13.0 cps; damping at station 386: when $x_o(G) = 0.43$, $g = 0.032$ and when $x_o(G) = 0.178$, $g = 0.17$.

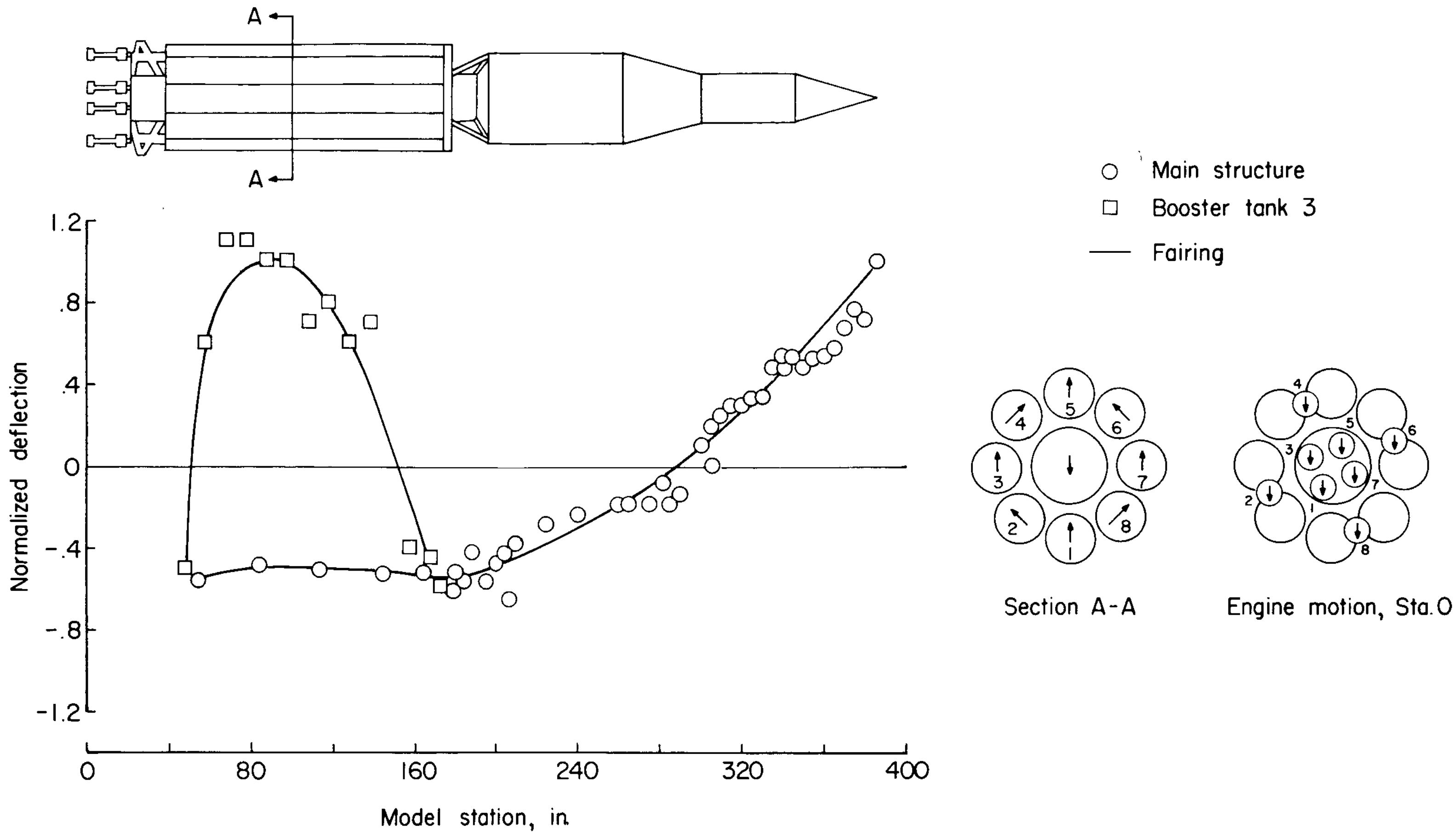


Figure 18.- First cluster mode of 1/5-scale Saturn. Booster tanks 48 percent full; frequency, 26.0 cps; damping at station 164: when $x_o(G) = 0.078$, $g = 0.23$ and when $x_o(G) = 0.032$, $g = 0.011$.

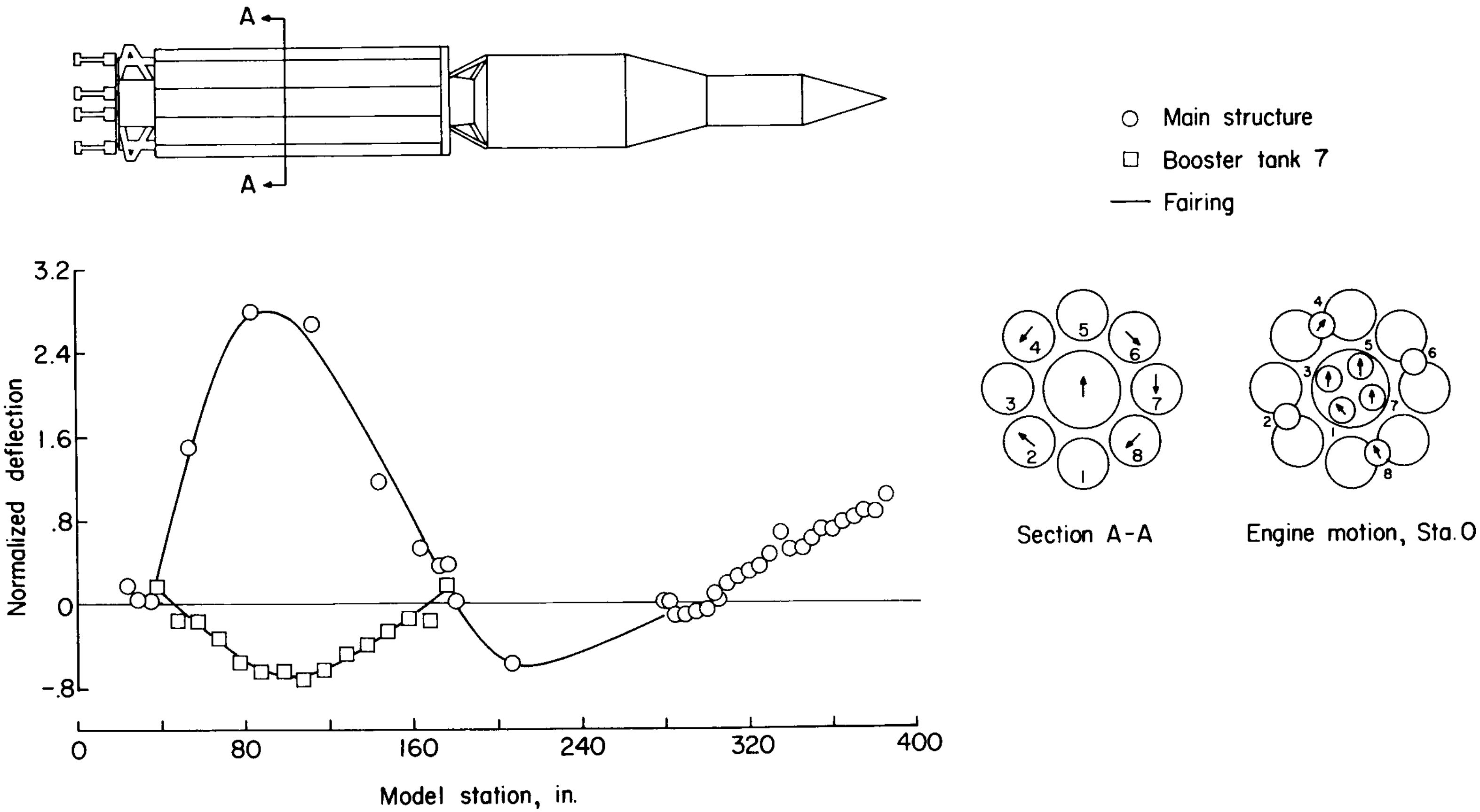


Figure 19.- Second cluster mode of 1/5-scale Saturn. Booster tanks 48 percent full; frequency, 33.9 cps.

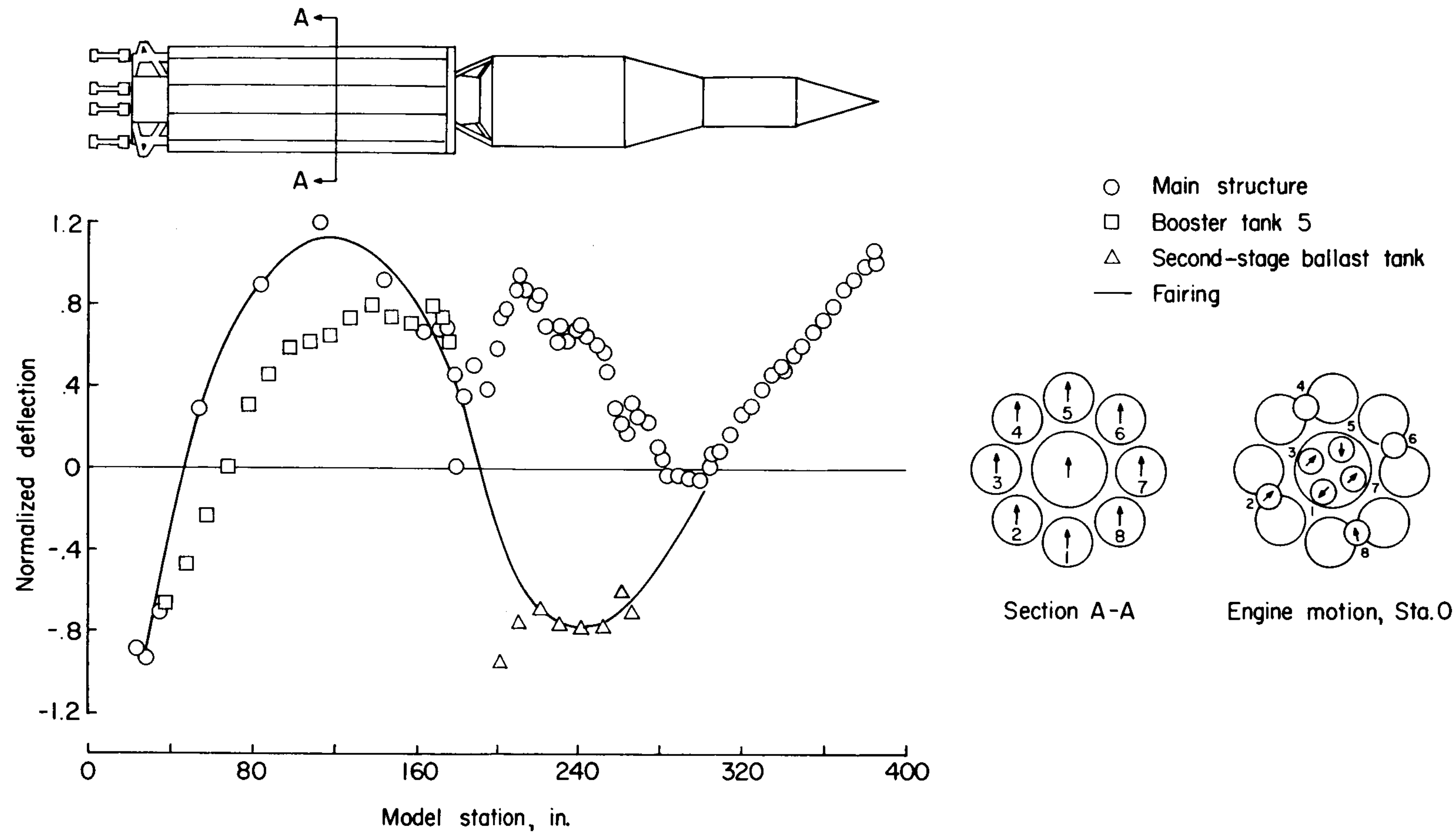


Figure 20.- Second bending mode of 1/5-scale Saturn. Booster tanks 48 percent full; frequency, 38.9 cps.

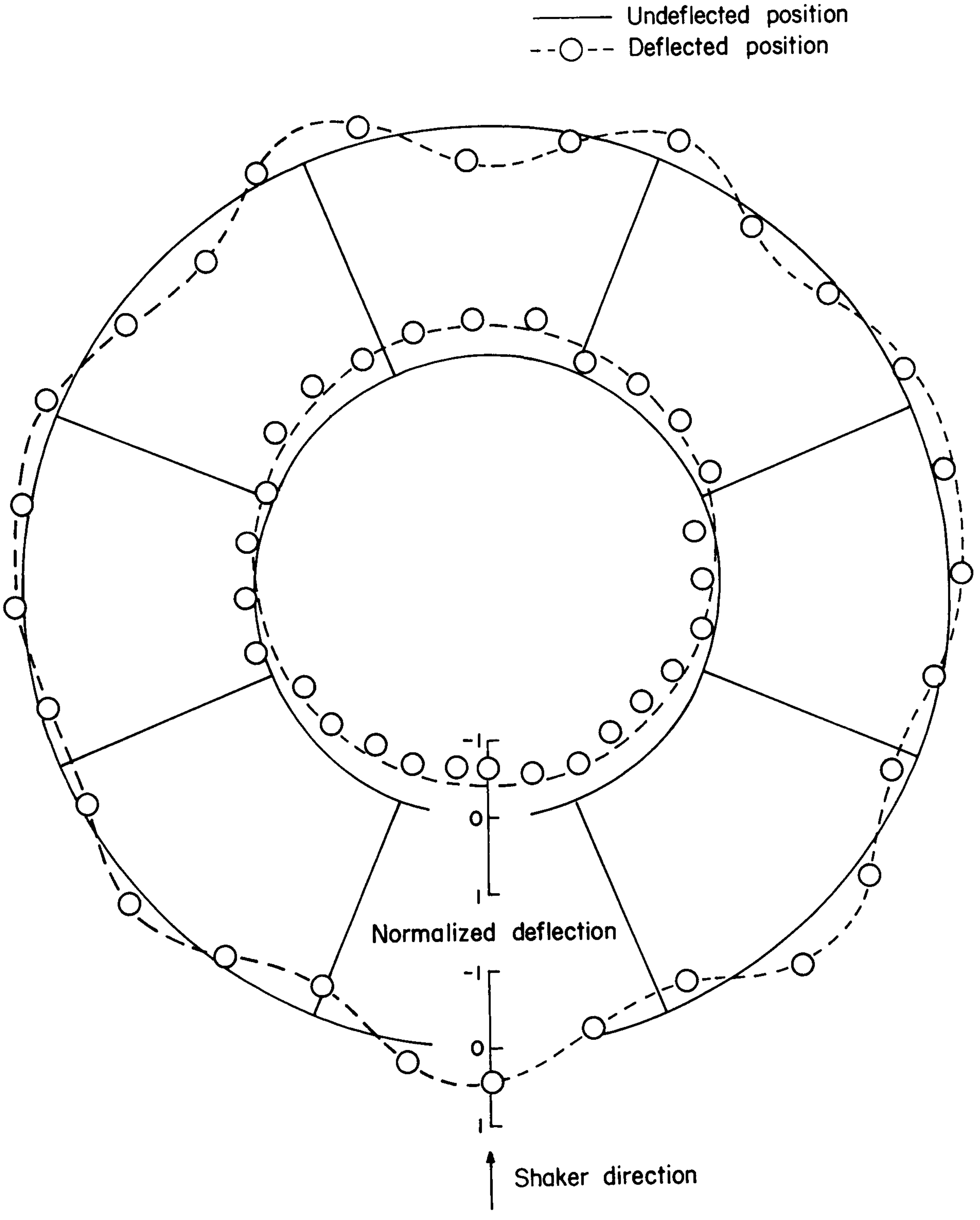


Figure 21.- Cross-section mode shape at station 210. Second bending mode; frequency, 38.9 cps; booster tanks 48 percent full.

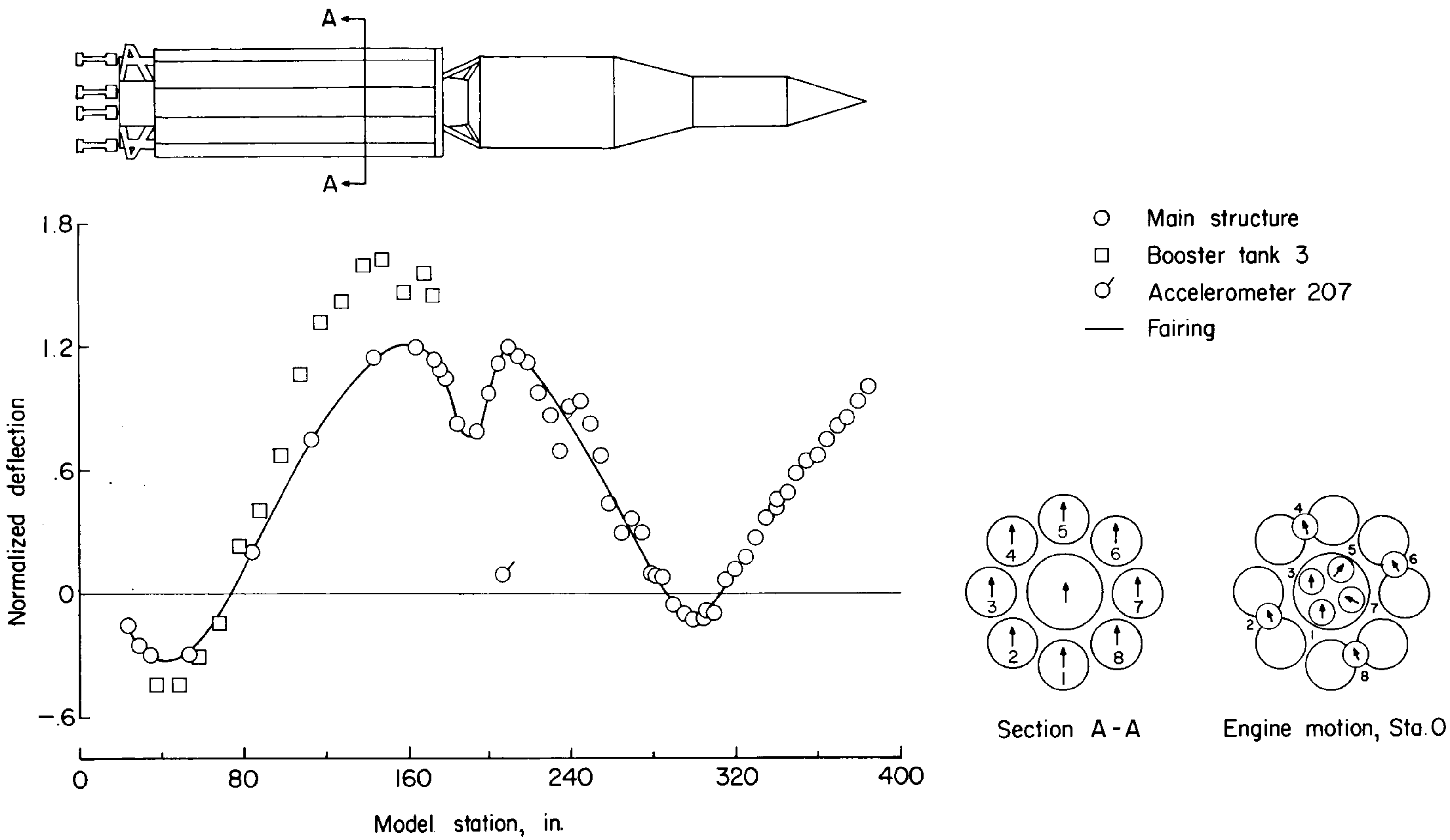


Figure 22.- Third bending mode of 1/5-scale Saturn. Booster tanks 48 percent full; frequency, 47.8 cps; damping at station 180: when $x_o(G) = 0.065$, $g = 0.017$.

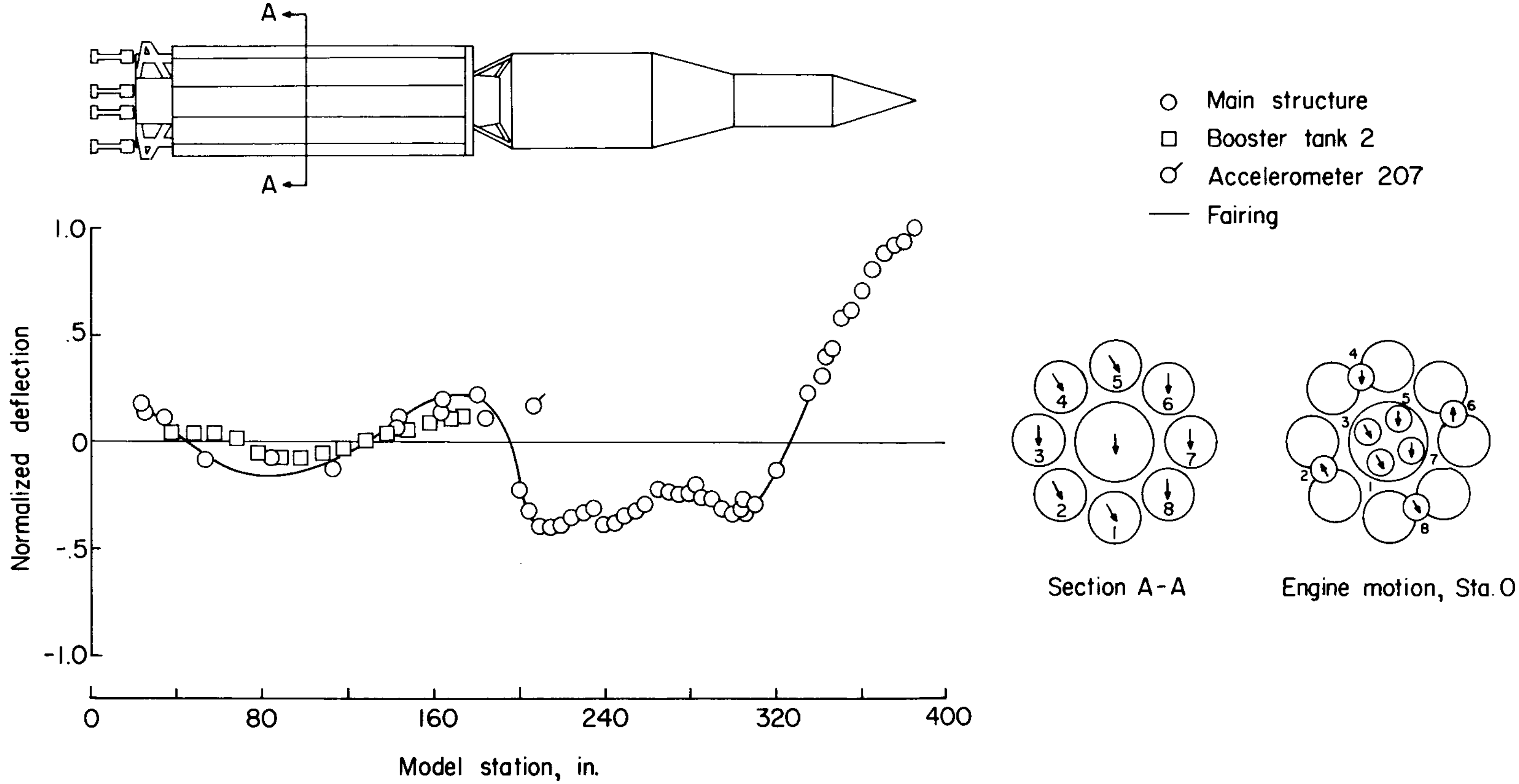


Figure 23.- Fourth bending mode of 1/5-scale Saturn. Booster tanks 48 percent full; frequency, 60 cps; damping at station 386: when $x_o(G) = 0.539$, $g = 0.011$ and when $x_o(G) = 0.346$, $g = 0.007$.

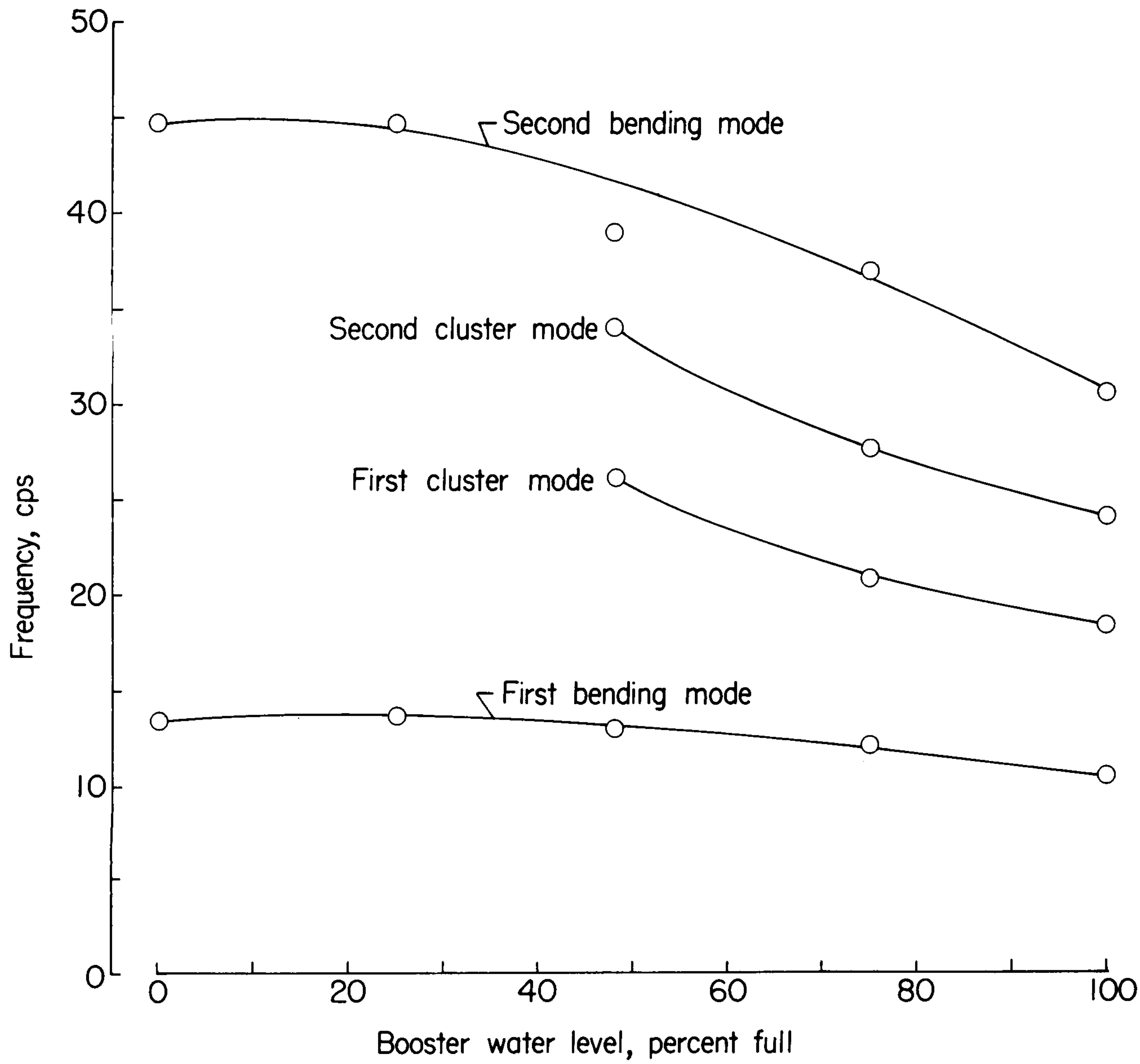


Figure 24.- Variation of resonant frequency with booster water level for 1/5-scale Saturn model.

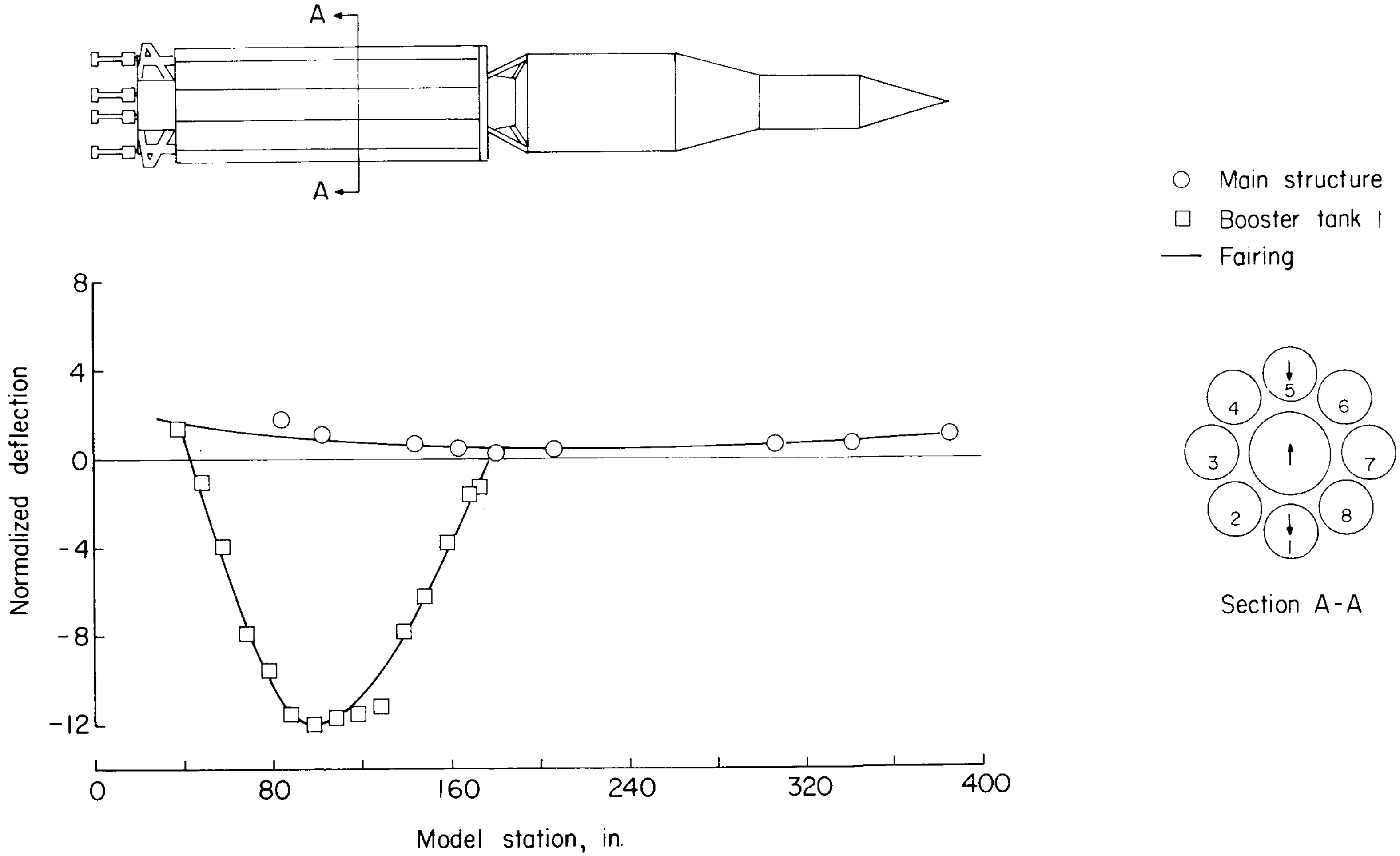


Figure 25.- Outer fuel tank mode of 1/5-scale Saturn. Booster tanks full; frequency, 9.1 cps.

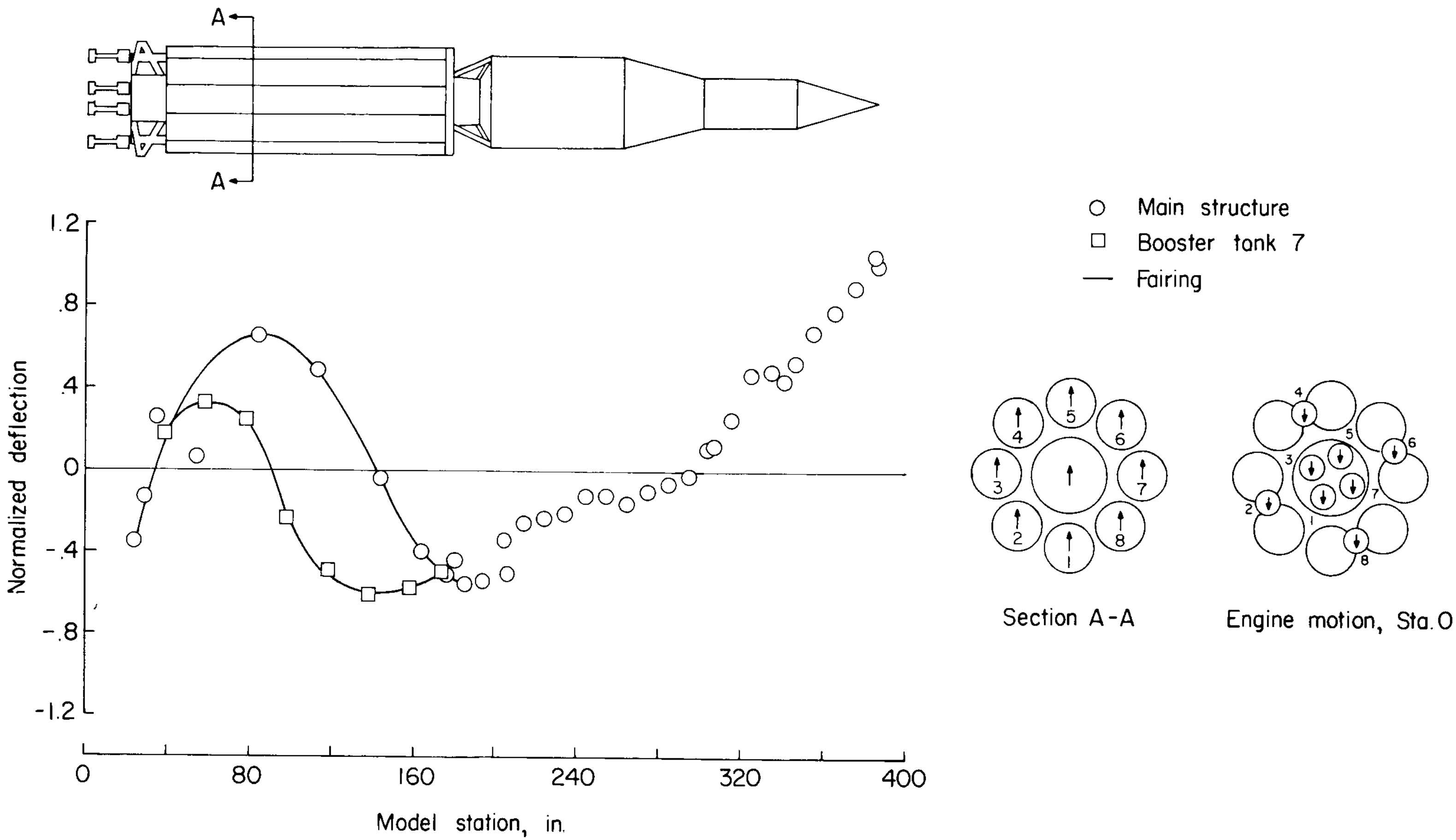
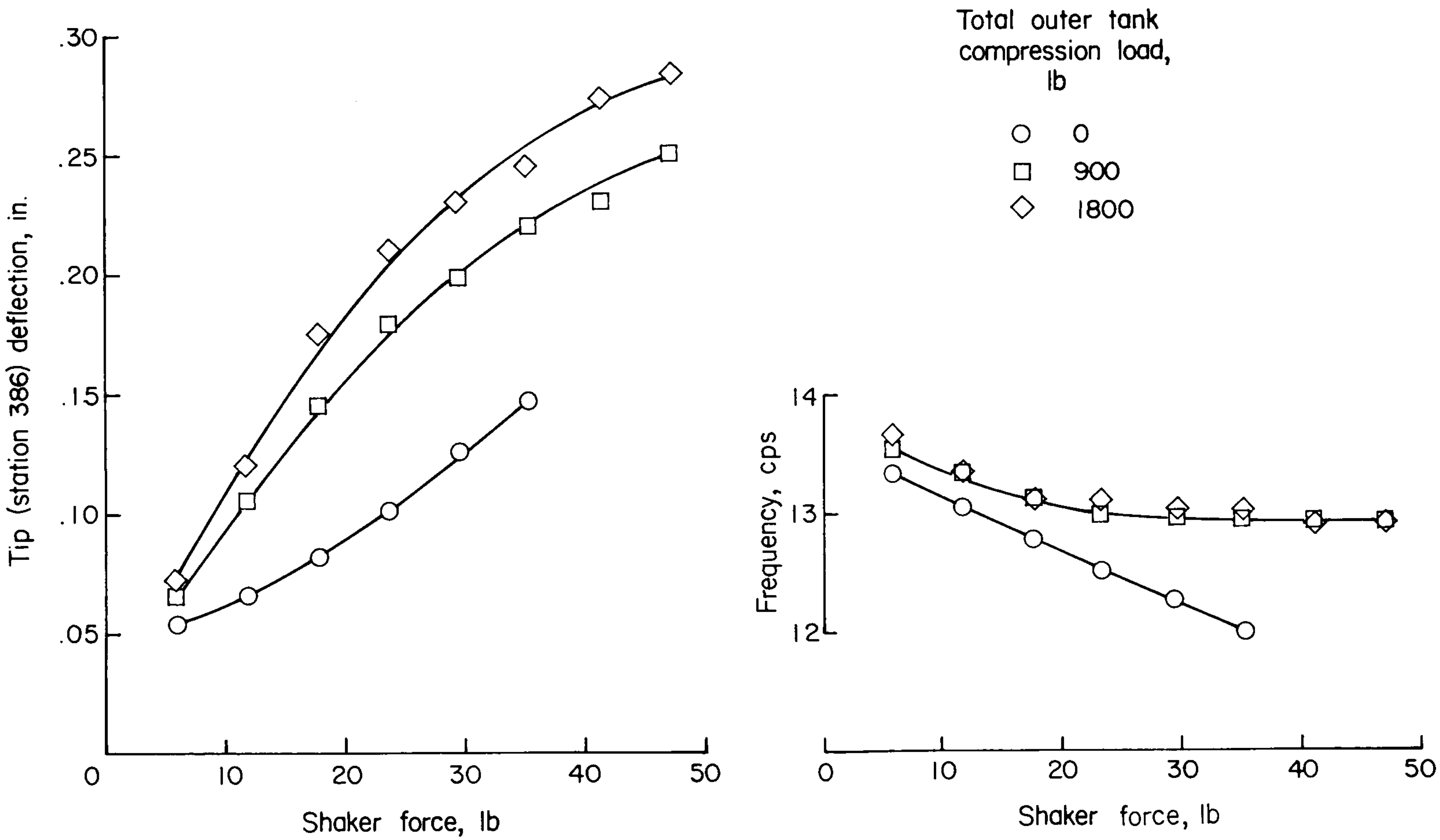


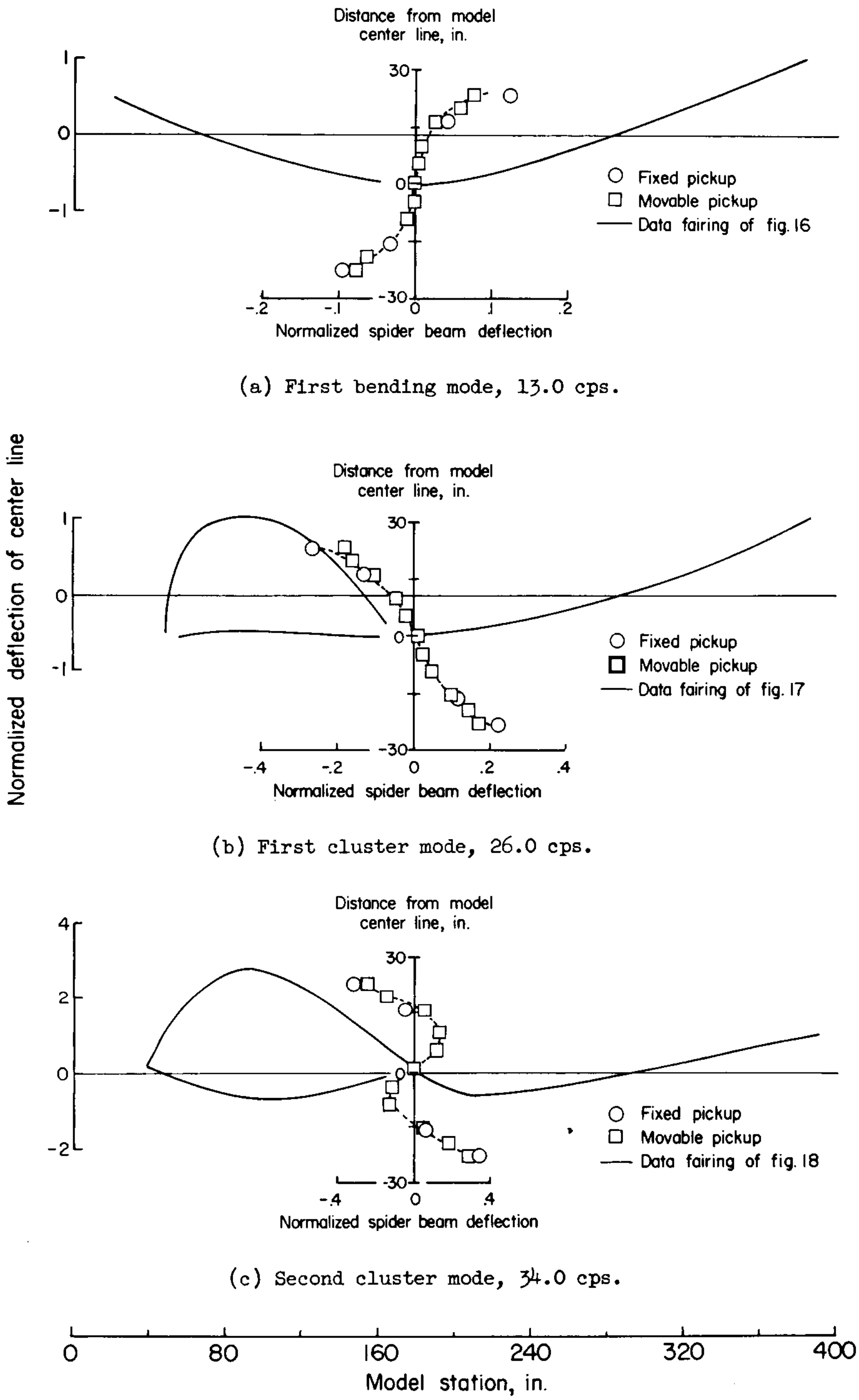
Figure 26.- Mode shape associated with third response peak. Booster tanks 100 percent full; 1/5-scale Saturn model; frequency, 24.0 cps; damping at station 386: when $x_o(G) = 0.098$, $g = 0.014$.



(a) Deflection against shaker force.

(b) Frequency against shaker force.

Figure 27.- Variation of resonant frequency and amplitude with shaker input force. Booster tanks 48 percent full; 1/5-scale Saturn model; first bending mode.



(a) First bending mode, 13.0 cps.

(b) First cluster mode, 26.0 cps.

(c) Second cluster mode, 34.0 cps.

Figure 28.- Mode shape showing deflections of the spider beam.